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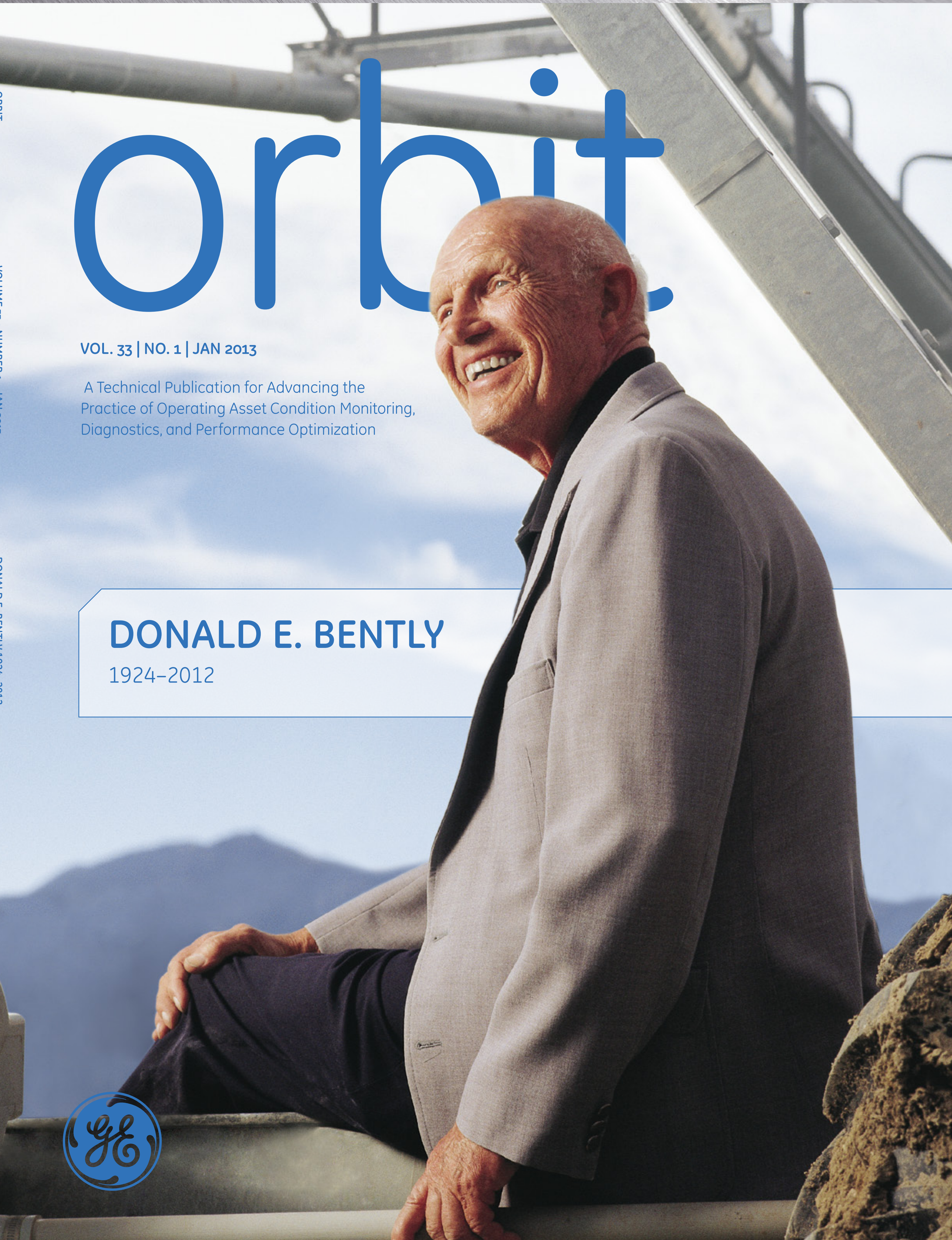
DONALD E. BENTLY 1924–2012



orbit

VOL. 33 | NO. 1 | JAN 2013

A Technical Publication for Advancing the
Practice of Operating Asset Condition Monitoring,
Diagnostics, and Performance Optimization

DONALD E. BENTLY

1924–2012

Editor's Notepad

Gary Swift
Editor
Orbit Magazine
gary.swift@ge.com

Greetings, and welcome to *Orbit!* With the passing of Donald E. Bently, founder of the original Bently Nevada Corporation (BNC), it is appropriate to mention his vital importance to our business, as well as to the entire field of machinery protection, diagnostics and condition monitoring. We have included a small In-Memoriam piece that was kindly provided by his family. And our lead article, which includes some guidelines for application of eddy current proximity transducers, is itself a fitting tribute to his lasting legacy. We have also included a very brief history of BNC and a follow-on article that celebrates our 10 years as part of GE

In addition to being an engineer and entrepreneur, Bently was also a philanthropist and environmentalist. His contributions to education and to the local Carson Valley community have been very generous over the years. My own daughter attended undergraduate classes at our local Western Nevada College campus, which was built on land that Bently donated specifically for that purpose. His contributions to the vibration monitoring industry are familiar to many of our readers, but some of his other business accomplishments are less widely known.

Bently grew up in Iowa, in the heartland of America, and loved animals and agriculture. In addition to founding Bently Nevada Corporation, he also founded other innovative businesses here in western Nevada that pioneered the use of sustainable agriculture and renewable fuels. Our cover photo shows him with one of his pieces of farm equipment, surveying his crops in the Carson Valley.

His agriculture business is focused on developing effective practices with cattle, crops and compost production, managing 50,000 acres of land and irrigation reservoirs. His deep interest in sustainability and conservation extended to a related business that is dedicated to research & development of the production and distribution of renewable fuels. This operation creates biodiesel fuel mainly from recycled cooking oil, and includes used cooking oil collection as a service to the restaurant industry.

I can say from personal experience that the garlic Don grew here was delicious, and judging from the contented expressions of the cattle I've seen eating his silage, the same thing can be said for his alfalfa!

Cheers!
Gary

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Design Coordination: **Eileen O'Connell**
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CONTRIBUTORS
GE Oil & Gas
Bob Craft
Walid El-Said
John Kingham
Nate Littrell
Mike Lockas
Don Marshall
Aarti Taneja
Joe Taylor
Dan Walmsley
Mark Werkheiser
Billy Wise

Bently Family Holdings CA LP
Brady J. Frey

Harker Enginuity, Inc.
Roger Harker

CREDITS
Bently Nevada Communications
Nik Noel
Holly Spiers

Questions, suggestions, and letters to the editor may be addressed to:
ORBIT Magazine
1631 Bently Parkway South
Minden, Nevada USA 89423
Phone: 775.782.3611
Fax: 775.215.2855
e-mail: orbit@ge.com

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THE LIFE OF A GREAT MAN

A history of warmth, intelligence, and prestige

Donald E. Bently was founder, owner and Chief Executive Officer of Bently Nevada Corporation, and President of Bently Pressurized Bearing Corporation.

He pioneered the successful commercial use of the eddy current proximity transducer to measure vibration in rotating machinery. This led to the development of data acquisition and processing systems and related services, and created the foundation of a new discipline of Mechanical Engineering, "Diagnostics of Machinery Malfunctions."

> "DON WAS A PATRIOT WHO WANTED TO SEE HIS COUNTRY PRESERVE ITS CHANCES TO CREATE PROSPERITY AND MAINTAIN PEACE AND SECURITY."
> — **John Lenczowski**
> Director, Institute of World Politics.

Mr. Bently was active in research on the dynamic behavior of rotating machinery. He published more than 50 papers on the subject of rotating machinery diagnostics using vibration monitoring. Mr. Bently received a Bachelor of Science Degree in Electrical Engineering (with distinction) in 1949, as well as a Master's Degree in Electrical Engineering in 1950, from the University of Iowa. He also did postgraduate work at the University of California at Berkeley. He was a registered professional Engineer in Electrical Engineering in both Nevada and California and a senior member of the IEEE.

> "ON THIS TRIP I ENJOYED GETTING A GLANCE AT ONE PHASE OF DON'S CHARACTER, HIS DEEP INTERESTS IN NATURE, ANIMAL, AND THE HISTORY OF CULTURE."
> — **Dr. Shuhei Izumi**
> Guest Professor, Nagasaki Institute of Applied Science

Mr. Bently was also a Foreign Member of the St. Petersburg Academy of Engineering in Russia (1992) and a Visiting Scholar of Tsinghua University in Beijing, China (1992). He was a trustee of the Institute of World Politics, and a member of the ASME Industrial Advisory Board.

Mr. Bently was honored as Nevada's outstanding inventor for 1983. In 1987, he was awarded an honorary Doctorate in Engineering by the University of Nevada, Reno. In 1992, Mr. Bently was selected to be the first person to receive the Vibration Institute's DECADE Award. ■

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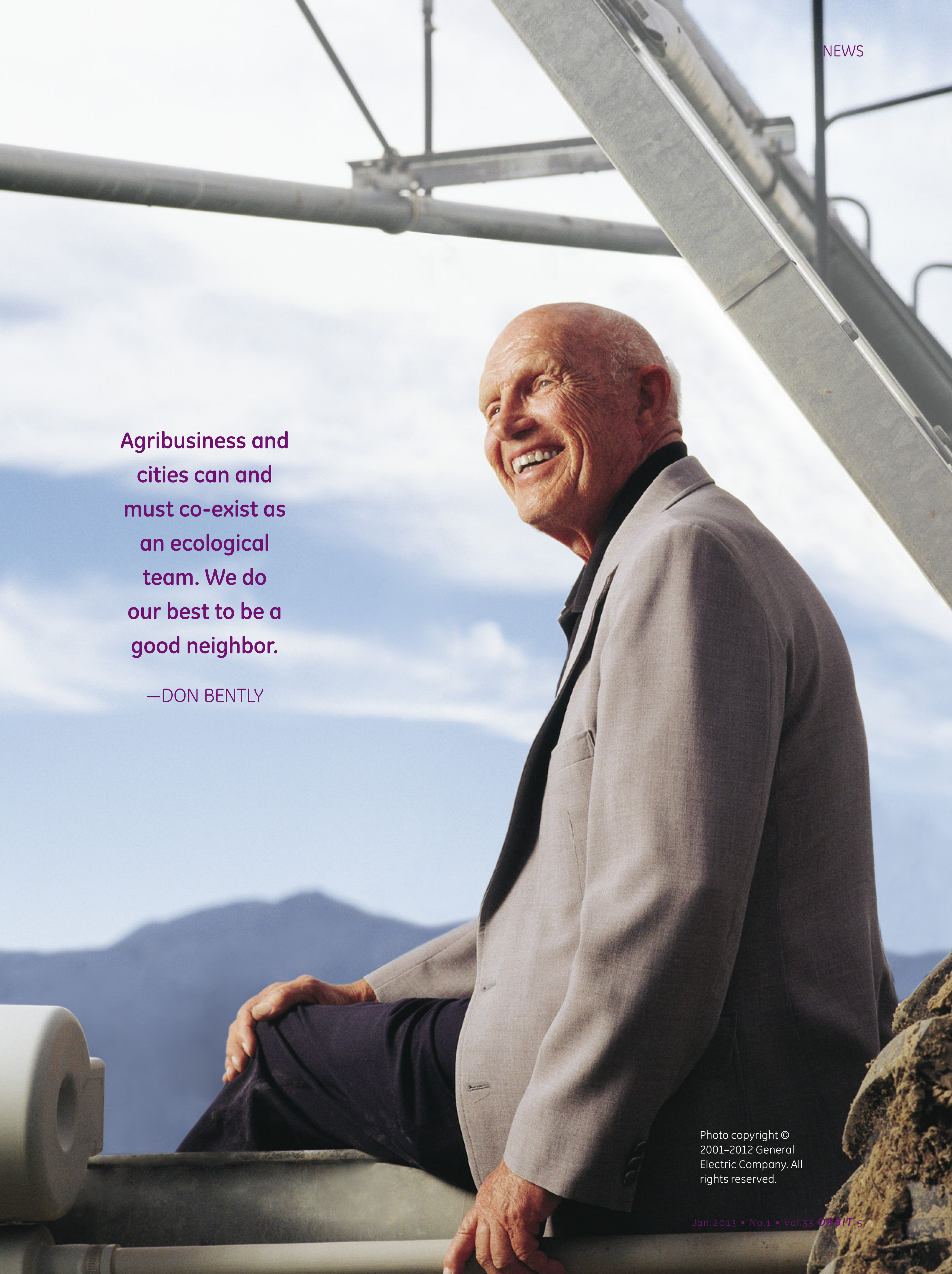

Agribusiness and cities can and must co-exist as an ecological team. We do our best to be a good neighbor.

—DON BENTLY

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CELEBRATING TEN YEARS WITH GE

EMPLOYEES AT GE'S MINDEN, NEVADA, USA FACILITY POSE FOR AN ANNIVERSARY PHOTO

Photo copyright © 2012 Belinda Grant Photography. All rights reserved. Used with permission.

TRADITIONALLY, the substance used to represent a 10-year wedding anniversary is tin. This element seems more humble than some of the other anniversary gifts, such as silver for the 25th year, pearls for the 30th year, or gold for the 50th year. But, before we get to the finer successes of the marriage between GE and Bently Nevada, it is worth noting tin's highly malleable nature, its resistance to corrosion and its abundance as an element with the largest number of stable isotopes (10) in the chart of the nuclides. Its value is multiplied when it is combined with other elements to create an alloy, and tin has proven itself to be useful to humans since the Bronze Age. It seems an appropriate metal to represent the very mettle and collective heritage of our own unique partnership.

A Rich History

For more than half a century, Bently Nevada has demonstrated its rich heritage of great people through smart, differentiated technology solutions and innovative services that help our customers remain at the forefront of their industries. That tradition was borne by none other than the company's founder, Don Bently. In the 1950s, Bently formed Bently Scientific Company in his garage in Berkeley, California. He began his business as the first to transistorize the design of eddy-current sensors, making them commercially viable.

A successful one-man operation, Bently Scientific became Bently Nevada in 1961 when Bently moved the company to its current headquarters in Minden, Nevada. A year later, the fledgling company sold its first monitoring system and OEMs began installing proximity probes on their machines. By the late 1960s, Bently Nevada was experiencing tremendous growth and making significant progress in the development of protection monitoring systems and training services.

Three decades later, the company that sprung from one man's California garage boasted 10,000 products and 100 offices in 42 countries, with manufacturing plants on two continents. The company had pioneered a condition monitoring systems industry that helped manufacturers protect their most valuable and critical plant assets. By the turn of the twenty-first century, Bently Nevada, which had remained a largely hidden jewel in the Nevada desert up until that point, emerged as a ripe acquisition target for an industry powerhouse.

[See the Bently Nevada history article on page 24 for a more detailed timeline of significant milestones — Editor]

A Melding of Businesses

One of the concerns when GE acquired Bently Nevada in January 2002 was the potential to lose the culture and identity of the Bently Nevada products and employees. Acquisition Leader Brian Palmer, now president and CEO of GE's Measurement & Control business, valued Bently's existing culture, brand, and business strategy so much that he recognized an opportunity to enhance GE's own brand and business while doing the same for Bently Nevada.

Palmer devoted resources to developing new technology and exposing new manufacturing areas to the value of Bently's products and services. He only had one mandate from GE Energy CEO John Rice: Bently Nevada will lose no customers as a result of the GE acquisition. With Bently Nevada in the fold, GE was able to offer a unique suite of complementary and tightly integrated technologies that enabled customers to mitigate their operating asset risks.

GE's commitment to Bently's existing customers resulted in better service, better products, and a willingness to drive customer value. With Bently's technology, GE began transitioning from its traditional stable of oil & gas and power generation-focused companies to broader applications in industrial businesses that also deployed rotating equipment and plant assets that required continuous, online monitoring. Accordingly and appropriately, there was no name change for the product line; Bently Nevada remains Bently Nevada to this very day – ten years later. The name is synonymous with expertise and customer value.

Excellence Continues

A decade after the GE acquisition, it is appropriate to ask what's next. The answer is that Bently Nevada will continue to design, manufacture, and market products and services that help its customers succeed. As the largest exporter in the state of Nevada, more than 90 percent of our products are still locally manufactured right here in Minden. More than 1,500 strong, Bently Nevada's global team remains committed to investing in the technology solutions that have made Bently Nevada the resilient company that it is today.

But like any competitive industry leader, we continuously strive to uncover new sources of innovation—both here in the United States and around the world—to create smart, differentiated technology solutions that help our customers remain at the forefront of their industries. That commitment to our customers was demonstrated by the 2011 acquisition of New Zealand-based Commtest Instruments, a company recognized globally for its leadership and innovation in portable vibration analysis and monitoring instruments. This strategic acquisition has enabled us to provide customers with an enhanced suite of integrated condition monitoring solutions that take into account the health of the entire plant.

And it doesn't stop there. In addition to launching a new series of innovative, portable solutions, we continue to make forward-looking technology investments, including a monitoring system that was engineered to be an easy retrofit for systems that are nearing the end of their service life. We have plans to unveil more distributed systems and software in the near future, along with a number of exciting new technologies that align with our vision to unite all of our offerings into a comprehensive, plant-wide condition monitoring experience for our customers.

Here's to our ten-year "tin" anniversary and to imagining all the wonderful things that will come in the next ten years, when our 20th anniversary will be symbolically commemorated by the gift of china. ■

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> FOR MORE THAN HALF A CENTURY, BENTLY NEVADA HAS DEMONSTRATED ITS RICH HERITAGE OF GREAT PEOPLE THROUGH SMART, DIFFERENTIATED TECHNOLOGY SOLUTIONS AND INNOVATIVE SERVICES THAT HELP OUR CUSTOMERS REMAIN AT THE FOREFRONT OF THEIR INDUSTRIES.

COLORS OF INDIA

Our India Team celebrated the 'Colors of India' with Brian Palmer, President & CEO, GE Measurement & Control, late in 2012. Palmer's objective was to gain deeper insights into businesses, product lines, functions, and services, and to interact with employees and key customers at a variety of locations.

EVENING FESTIVITIES AT THE GURGAON OFFICE
LEFT TO RIGHT: Manoj Chandrasekharan, Anurag Bhagania, Brian Palmer, Banmali Agrawala, Ajai Shukla.

ASHISH BHANDARI DELIVERS CLOSING REMARKS

GE
Measurement & Control
Colors of India

Palmer addressed employees in Gurgaon, stressing the need to focus on continuing to deliver for our customers despite challenging conditions. In addition to discussing business, the group enjoyed light-hearted activities such as taking novelty photographs and watching the performance of an expert dance troupe. A grand surprise drawing resulted in selected participants performing a "cat-walk" while wearing costume props.

Highlight of the event was a mock television game-show called 'Kaun Banega Colorpati' (Who Will Become Colorful) where Palmer was quizzed on his knowledge of India and Banmali Agrawala, President & CEO, GE Energy India had to answer questions about GE. Both were winners, receiving an oversized joke cheque for "$100 billion USD."

The event ended with a closing note from Ashish Bhandari, Region Head, Measurement & Control – India, and participants taking their framed souvenir photographs home. Palmer spent several more days visiting local Indian facilities in Coimbatore and Mumbai where he addressed assemblies of employees, shared lunch with a select group of employees, met with key customers and attended business review sessions. He headed home with a renewed appreciation for the colourful and diverse culture of India. ■

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FIELD ENGINEER PROGRAM (FEP) UPDATE

Another class of Bently Nevada FEP delegates graduated recently after four weeks of Systems Engineer training at our Minden facility. Following classroom and laboratory training in western Nevada, they traveled to GE facilities in Houston, Texas, for mentored On the Job Training (OJT) sessions in Systems Engineering[1] tasks with full-sized industrial machines. Students who are entering Machinery Diagnostic Services (MDS) assignments completed an additional two weeks of MDS-specific training before heading to their home regions.

THIS SMALL CLASS IS TYPICAL OF OUR INTERNATIONAL WORKFORCE, REPRESENTING CANADA, INDONESIA, SINGAPORE, UK AND USA. FROM LEFT TO RIGHT: Dan Walmsley (Instructor), Chris Baldwin, Andri Hidayat, Melvin Wai Yin, Dan Kosuda, Dan Freeman, Stephen Coe, Aniel Padrino, Jose Hernandez & Greg O'Drobinak.

Houston OJT Lab

Following the classroom portion of their FEP training, delegates continued their learning at the Houston Granite facility. Structured OJT tasks gave them the opportunity to gain hands-on experience prior to entering field and customer sites. The OJT lab exercises replace many of the required training tasks that once had to be completed in the field with a mentor. At the Granite facility, field engineers installed radial proximity, seismic, and axial thrust probes on various machine types, including steam turbine generators, gas turbines, small compressors, and gearboxes.

What the OJT lab does not replace is the Service Manager's judgment and discretion. Field Engineers still need to participate in certain types of jobs (complex, hazardous, etc.) with mentors before being allowed to perform such jobs on their own.

OJT labs also do not address the "people" skills that can only be gained with actual field experience working with customers. To address this need, FEs are also required to spend a minimum of 40 hours in the field under evaluation by their mentors while performing 70% of the job tasks without assistance. Only when they have satisfactorily completed this evaluated field time will the Service Manager designate them as being certified to work on their own.

The OJT lab at the Houston Granite facility is being used as a model for additional Bently Nevada OJT labs. Labs in Florence, Italy, and Jandakot, Australia, are being designed and are scheduled to open in 2013. Watch future issues for more information on these new facilities as they are completed and put into service. ■

NOTE 1: Bently Nevada Systems Engineers perform a variety of onsite services, including installation, troubleshooting, and repair of condition monitoring and protection systems (transducers, monitor systems and software). MDS Engineers specialize in machinery diagnostics, both remotely and onsite, using a combination of permanently-installed and temporary condition monitoring equipment and diagnostic software.

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Photos by Bernie Garner

ANDRI HIDAYAT installs a probe cable connector protector on a turbocompressor

MELVIN WAI YIN AND JOSE HERNANDEZ instrument a gearbox.

GREG O'DROBINAK AND CHRIS BALDWIN work on a small screw-type air compressor

2013 TRAINING SCHEDULE

If you are interested in learning more about your Bently Nevada* Asset Condition Monitoring products, or applied topics such as machinery diagnostics and balancing, here is our training course calendar for 2013. These public courses are presented in a wide variety of locations and languages to accommodate the needs of our global customers.

NOTE: This calendar was up to date at the time of printing, but schedules are subject to change. For the latest updated information, visit our training website: **http://ge-energy.turnstilesystems.com/**

ASIA

COURSE TITLE	DURATION (DAYS)	CITY	COUNTRY	START DATE	LANGUAGE
Transducer and 3500 Operation & Maintenance	5	Kuala Lumpur	Malaysia	18-Feb	English
Transducer and 3500 Operation & Maintenance	5	Singapore	Singapore	4-Mar	English
ADRE & 408 DSPi System	3	Seoul	Korea	4-Mar	Korean
System 1 Fundamentals	3	Seoul	Korea	6-Mar	Korean
Machinery Diagnostics	5	Perth	Australia	11-Mar	English
Transducer and 3500 Operation & Maintenance	5	Seoul	Korea	12-Mar	Korean
Machinery Diagnostics	5	Seoul	Korea	18-Mar	Korean
Advanced Machinery Dynamics	5	Perth	Australia	18-Mar	English
System 1 Fundamentals	3	Perth	Australia	25-Mar	English
Transducer and 3500 Operation & Maintenance	5	Sydney	Australia	29-Apr	English
Transducer and 3500 Operation & Maintenance	5	Perth	Australia	27-May	English
Reciprocating Compressor Condition Monitoring & Diagnostics	3	Brisbane	Australia	10-Jun	English
Transducer and 3500 Operation & Maintenance	5	Singapore	Singapore	10-Jun	English
Machinery Diagnostics	5	Sydney	Australia	17-Jun	English
Transducer and 3500 Operation & Maintenance	5	Kuala Lumpur	Malaysia	17-Jun	English
Machinery Diagnostics	5	Seoul	Korea	17-Jun	Korean
Machinery Fundamentals / Applied Diagnostics	5	Sydney	Australia	24-Jun	English
System 1 Fundamentals	3	Kuala Lumpur	Malaysia	24-Jun	English

For more information on Asian training courses, contact the Regional Training Manager (RTM), Daniel Ong, daniel.ong@ge.com.

CANADA

COURSE TITLE	DURATION (DAYS)	CITY	START DATE
3500 Operation & Maintenance	3	Edmonton	05-Feb
3500 Operation & Maintenance	3	Edmonton	14-May
3500 Operation & Maintenance	3	Edmonton	08-Oct
3500 Operation & Maintenance	3	Fort McMurray	05-Mar
3500 Operation & Maintenance	3	Fort McMurray	05-Nov
System 1 Fundamentals	3	Edmonton	19-Feb
System 1 Fundamentals	3	Edmonton	17-Sep
System 1 Fundamentals	3	Edmonton	03-Dec
System 1 Fundamentals	3	Fort McMurray	09-Apr
System 1 Fundamentals	3	Fort McMurray	26-Nov

For more information on training courses in Canada, contact the RTM, Mark Werkheiser, mark.werkheiser@ge.com.
All Canadian courses are presented in English.

CHINA

COURSE TITLE	DURATION (DAYS)	CITY	START DATE
3500 System Operation & Maintenance	3	Shanghai	23-Jan
Fundamentals of Vibration and Transducer Operation	2	Shanghai	18-Mar
3500 System Operation & Maintenance	3	Shanghai	20-Mar
System 1 Fundamentals	3	Shanghai	25-Mar
Fundamentals of Vibration and Transducer Operation	2	Shanghai	22-Apr
3500 System Operation & Maintenance	3	Shanghai	24-Apr
System 1 Fundamentals	3	Shanghai	22-May
Machinery Diagnostics	5	Shanghai	27-May
ADRE 408	3	Shanghai	4-Jun
Fundamentals of Vibration and Transducer Operation	2	Shanghai	24-Jun
3500 System Operation & Maintenance	3	Shanghai	26-Jun

For more information on Chinese training courses, contact the RTM, Yingbo Cui, Yingbo.Cui@ge.com.
All Chinese courses are presented in Mandarin.

EUROPE

COURSE TITLE	DURATION (DAYS)	CITY	COUNTRY	START DATE	LANGUAGE
Machinery Diagnostics (With System 1)	5	Florence	Italy	18 Mar	English
Machinery Diagnostics (With System 1)	5	Florence	Italy	02 Dec	English
Machinery Diagnostics (With ADRE Sxp)	5	Florence	Italy	28 Jan	English
Machinery Diagnostics (With ADRE Sxp)	5	Florence	Italy	06 May	English
Machinery Fundamentals/Applied Diagnostics	5	Florence	Italy	04 Feb	English
Machinery Fundamentals/Applied Diagnostics	5	Florence	Italy	13 Mar	English
Machinery Fundamentals/Applied Diagnostics	5	Florence	Italy	18 Nov	English
3500 System Operation & Maintenance	3	Florence	Italy	22 May	English
3500 System Operation & Maintenance	3	Florence	Italy	11 Sep	English
System 1 Fundamentals	3	Florence	Italy	07 Jan	English
System 1 Fundamentals	3	Florence	Italy	27 Feb	English
System 1 Fundamentals	3	Florence	Italy	03 Apr	English
Bently Performance – Centrifugal Compressor Performance	5	Florence	Italy	24 Jun	English
Advanced Machinery Dynamics	5	Florence	Italy	20 May	English
ADRE 408 Fundamentals	3	Florence	Italy	16 Jan	English
ADRE 408 Fundamentals	3	Florence	Italy	28 Aug	English
Reciprocating Compressor Condition Monitoring and Diagnostics	3	Florence	Italy	23 Apr	English
Machinery Diagnostics (With System 1)	5	Rotterdam	Holland	08 Apr	English
Machinery Diagnostics (With System 1)	5	Rotterdam	Holland	01 Jul	English
Machinery Diagnostics (With ADRE Sxp)	5	Rotterdam	Holland	28 Oct	English
System 1 Fundamentals	3	Rotterdam	Holland	06 Nov	English
System 1 Fundamentals	3	Rotterdam	Holland	17 Dec	English
Transducer Installation/Vibration Fundamentals	2	Warrington	UK	11 Feb	English
3500 System Operation & Maintenance	3	Warrington	UK	13 Feb	English
Transducer Installation/Vibration Fundamentals	2	Warrington	UK	13 May	English
3500 System Operation & Maintenance	3	Warrington	UK	15 May	English

Transducer Installation/Vibration Fundamentals	2	Warrington	UK	02 Dec	English
3500 System Operation & Maintenance	3	Warrington	UK	04 Dec	English
System 1 Fundamentals	3	Warrington	UK	20 Feb	English
System 1 Fundamentals	3	Warrington	UK	10 Jun	English
System 1 Fundamentals	3	Warrington	UK	15 Oct	English
Machinery Diagnostics (With System 1)	5	Warrington	UK	04 Mar	English
Machinery Diagnostics (With System 1)	5	Warrington	UK	30 Sep	English
Machinery Diagnostics (With System 1)	5	Nantes	France	21 Jan	French
Machinery Diagnostics (With System 1)	5	Nantes	France	23 Sep	English
Machinery Diagnostics (With ADRE Sxp)	5	Nantes	France	22 Apr	French
Machinery Diagnostics (With ADRE Sxp)	5	Nantes	France	16 Dec	English
3500 System Operation & Maintenance	3	Nantes	France	24 Jul	French
ADRE 408 Fundamentals	3	Nantes	France	16 Apr	French
System 1 Fundamentals	3	Bergen	Norway	18 Sep	Dutch
System 1 Fundamentals	3	Bergen	Norway	21 Oct	Dutch
Reciprocating Compressor Condition Monitoring and Diagnostics	3	Bergen	Norway	09 Jul	English
Reciprocating Compressor Condition Monitoring and Diagnostics	3	Bergen	Norway	09 Sep	English
Bently Performance – Centrifugal Compressor Performance	5	Bergen	Norway	25 Nov	Dutch
ADRE 408 Fundamentals	3	Bergen	Norway	25 Jun	Dutch

For more information on European training courses, contact the RTMs, Luca Martino (Italy), luca.martino@ge.com, or Sandrine Hardy (France), Sandrine.Hardy@ge.com.

INDIA

COURSE TITLE	DURATION (DAYS)	CITY	START DATE
Transducer and 3500 Operation & Maintenance	5	Gurgaon	15-Apr
Transducer and 3500 Operation & Maintenance	5	Gurgaon	6-May
Machinery Diagnostics	5	Gurgaon	13-May

For more information on Asian training courses, contact the Regional Training Manager (RTM), Daniel Ong, daniel.ong@ge.com.
All Indian courses are presented in English.

LATIN AMERICA

COURSE TITLE	DURATION (DAYS)	CITY	COUNTRY	START DATE	LANGUAGE
3500 Operation and Maintenance	3	Mexico D.F.	Mexico	Mar 19	Spanish
Machinery Diagnostics	5	Mexico D.F.	Mexico	Jun18	Spanish
Maximizing the Benefits of System 1	3	Mexico D.F.	Mexico	May 21	Spanish
Machinery Diagnostics	5	Point-a-Pier	Trinidad	Jun 10	English
3500 Operation and Maintenance	3	Bogota	Colombia	Mar 5	Spanish
Machinery Diagnostics	5	Bogota	Colombia	Apr 22	Spanish
Maximizing the Benefits of System 1	3	Bogota	Colombia	Jul 2	Spanish
Machinery Diagnostics	5	Buenos Aires	Argentina	Apr 8	Spanish
3500 Operation and Maintenance	3	Buenos Aires	Argentina	Jul 9	Spanish
Maximizing the Benefits of System 1	3	Buenos Aires	Argentina	Sep 10	Spanish
Advanced Machinery Diagnostics	5	Buenos Aires	Argentina	Oct 7	Spanish
Advanced Machinery Diagnostics	5	Santiago	Chile	Nov 4	Spanish
Machinery Diagnostics	5	Santiago	Chile	Dec 9	Spanish
3500 Operation and Maintenance	3	Puerto La Cruz	Venezuela	Feb 19	Spanish
Machinery Diagnostics	5	Puerto La Cruz	Venezuela	Apr 8	Spanish
Maximizing the Benefits of System 1	3	Puerto La Cruz	Venezuela	Jun 10	Spanish
Reciprocating Compressor Diagnostics	3	Puerto La Cruz	Venezuela	Aug 5	Spanish
3500 Operation and Maintenance	3	Maracaibo	Venezuela	Feb 26	Spanish
Machinery Diagnostics	5	Maracaibo	Venezuela	Apr 15	Spanish
Maximizing the Benefits of System 1	3	Maracaibo	Venezuela	Jun 17	Spanish
Reciprocating Compressor Diagnostics	3	Maracaibo	Venezuela	Aug 12	Spanish

JUST AS WITH OUR SALES AND SERVICES OFFERINGS AROUND THE WORLD, OUR **GOAL** FOR CUSTOMER TRAINING IS TO MAKE IT AVAILABLE IN LOCAL LANGUAGES IN A WIDE VARIETY OF GLOBAL LOCATIONS.

Maximizing the Benefits of System 1	3	Campinas	Brazil	Apr 9	Portuguese
Maximizing the Benefits of System 1	3	Campinas	Brazil	Jun 4	Portuguese
Maximizing the Benefits of System 1	3	Campinas	Brazil	Sep 3	Portuguese
Maximizing the Benefits of System 1	3	Campinas	Brazil	Nov 5	Portuguese
3500 Operation and Maintenance	3	Campinas	Brazil	Apr 2	Portuguese
3500 Operation and Maintenance	3	Campinas	Brazil	May 7	Portuguese
3500 Operation and Maintenance	3	Campinas	Brazil	Aug 6	Portuguese
3500 Operation and Maintenance	3	Campinas	Brazil	Oct 7	Portuguese
Reciprocating Compressor Diagnostics	3	Campinas	Brazil	Apr 23	Portuguese
Reciprocating Compressor Diagnostics	3	Campinas	Brazil	May 14	Portuguese
Reciprocating Compressor Diagnostics	3	Campinas	Brazil	Jun 18	Portuguese
Reciprocating Compressor Diagnostics	3	Campinas	Brazil	Aug 13	Portuguese
3500+S1+MDS	10	Campinas	Brazil	Mar 11	Portuguese
3500+S1+MDS	10	Campinas	Brazil	Jul 15	Portuguese
3500+S1+MDS	10	Campinas	Brazil	Oct 21	Portuguese
Machinery Diagnostics	5	Campinas	Brazil	Apr 15	Portuguese
Machinery Diagnostics	5	Campinas	Brazil	Jul 1	Portuguese
Machinery Diagnostics	5	Campinas	Brazil	Sep 16	Portuguese
Machinery Diagnostics	5	Campinas	Brazil	Nov 25	Portuguese

For more information on Latin American training courses, contact the RTM, Eduardo Cote, eduardo.cote@ge.com.

MIDDLE EAST & AFRICA

For more information on Middle Eastern and African training courses, contact the RTM, Mohamed Shams, mohamed.shams@ge.com.

USA

COURSE TITLE	DURATION (DAYS)	CITY	START DATE
3500 Encore	3	Minden	15-Jan
Fundamentals of Vibration	2	Houston	4-Mar
3500 Operations & Maintenance	3	Houston	6-Mar
Wind Turbine Condition Monitoring	2	Minden	29-Jan
System 1 Fundamentals	3	Minden	12-Feb
ADRE 408	3	Houston	23-Apr
Machinery Diagnostics	5	Minden	25-Feb
3500 Operations & Maintenance	3	Houston	16-Apr
System 1 Fundamentals	3	Houston	12-Mar
Fundamentals of Vibration	2	Minden	4-Feb
3500 Operations & Maintenance	3	Minden	6-Feb
3500 Operations & Maintenance	3	Minden	7-May
System 1 Fundamentals	3	Minden	14-May
ADRE 408	3	Minden	22-Jan
Fundamentals of Vibration	2	Houston	3-Jun
3500 Operations & Maintenance	3	Houston	5-Jun
System 1 Fundamentals	3	Houston	11-Jun
Machinery Diagnostics	5	Houston	17-Jun
3500 Encore	3	Minden	18-Jun
Introduction to Vibration	2	Knoxville	7-Jan
Implementation Success Training	2	Knoxville	9-Jan
Balancing	1	Knoxville	11-Jan
Introduction to Vibration	2	Knoxville	4-Feb
Implementation Success Training	2	Knoxville	6-Feb
Balancing	1	Knoxville	8-Feb
Advanced Ascent/vbSeries	3	Knoxville	11-Mar

Balancing	1	Knoxville	14-Mar
Introduction to Vibration	2	Knoxville	15-Apr
Implementation Success Training	2	Knoxville	17-Apr
Balancing	1	Knoxville	19-Apr
Introduction to Vibration	2	Knoxville	13-May
Implementation Success Training	2	Knoxville	15-May
Balancing	1	Knoxville	17-May
Advanced Ascent/vbSeries	3	Knoxville	17-Jun
Balancing	1	Knoxville	20-Jun

For more information on training courses in USA, contact the RTM, Mark Werkheiser, mark.werkheiser@ge.com

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A VERY BRIEF BENTLY NEVADA HISTORY

It would be impossible to adequately chronicle more than five decades of Bently Nevada history within the pages of a single issue of Orbit magazine. But with the recent passing of our founder, Donald E. Bently, it is appropriate to include a brief summary of his legacy in this issue.

The story is familiar. A visionary entrepreneur invents a product and begins building it in his home, starting out very small and growing his business into an industry leader. In Bently's case, his small mail-order business grew be a truly global company, with an experienced Sales & Services force and offices in more than 40 different countries.

While researching this article, I had the enjoyable opportunity to talk with Roger Harker, who was President of Bently Nevada Corporation (BNC) from 1964 to 2002. He emphasized that the path to success for any business is to make effective strategic decisions to "do the right things." This was a core principle that allowed BNC to become very successful in the field of machinery protection, condition monitoring and diagnostics. –Editor.

Bently Nevada
Asset Condition Monitoring
3300 XL 5/8mm PROXIMITOR® SENSOR
PROXIMITOR
BENTLY NEVADA
MODEL 20885-01
SERIAL 124734
CAL 200mv mil
-18 VDC
COM
OUTPUT

NEW AND OLD: examples of Bently Nevada Proximitor* sensor illustrate many years of continuous improvement (3300 XL series on left and 3000 series on right)

1950s

New technology in search of an application

In his earliest experiments, Bently used miniature vacuum tubes. But recognizing the advantages of solid-state components, he quickly adapted the more reliable transistors that were becoming available by the mid-1950s. His early transducer systems began to be used by major Original Equipment Manufacturers (OEMs) in their research and development labs, but were not yet being applied to plant equipment in the field.

In the earliest days, Bently did everything himself with no additional employees. His philosophy was that if he built a useful product, sales would follow. He wasn't focused on a particular industry, but created designed-to-order "distance detectors" that were used to make very precise bench-top distance measurements in laboratory settings. Sales channels were via mail order only.

BENTLY
SCIENTIFIC COMPANY
BERKELEY 10, CALIFORNIA
ODEL
D-157
SERIAL
2743
DISTANCE DETECTOR

BENTLY SCIENTIFIC PRODUCT LABEL

NOSTALGIC VISIT TO THE GARAGE WORKSHOP IN BERKELEY, CALIFORNIA.

1953

For the first time, climbers reached the peak of Mt. Everest. Bently encountered eddy current proximity transducer technology while working as a control systems engineer in the aerospace industry. His employer was not interested in his suggestion to use electronics for control surface position feedback.

1954

First nuclear submarine launched. In his spare time, Bently developed basic circuit designs for transistorizing the eddy-current proximity transducer – which was originally pioneered by GE in the 1930s using vacuum tube-based circuits.

1955

Bently left his aerospace controls career and his pursuit of a doctorate degree to found Bently Scientific in his garage in Berkeley, California.

STRATEGIC DECISIONS

Leaving the aerospace industry to start his own business

Embracing the new solid-state electronics technology

1960s

Revolutionizing the way the world monitors machinery condition

During the 1960s, Bently hired people to help him with his business, starting with 5 employees in 1961 and reaching 150 by 1969. His machinery-focused view was that his products allowed better measurements as his probes could go "where the action is" inside the machines. His transducers were used increasingly by turbomachinery OEMs and in the hydrocarbon processing industries. The product line expanded to include proximity transducers, continuous monitors and portable test equipment. Sales shifted from mail-order to mostly partner representatives "reps." A factory-direct sales force was launched in 1967 in Houston, USA.

In the early 1960s, BNC transducer systems were often used in conjunction with third-party monitors that were not always set up properly. After dealing with several instances where the third-party monitor system were causing problems, Bently decided to start making monitors himself. This allowed BNC to offer a complete instrumentation system – from the probe in the machine, all the way to the monitor that processed the transducer signals.

1961

Yuri Gagarin first man in space. Bently Nevada Corporation (BNC) relocated to airport building in Minden, Nevada.

1962

First thrust position and radial vibration transducers delivered to large OEMs.

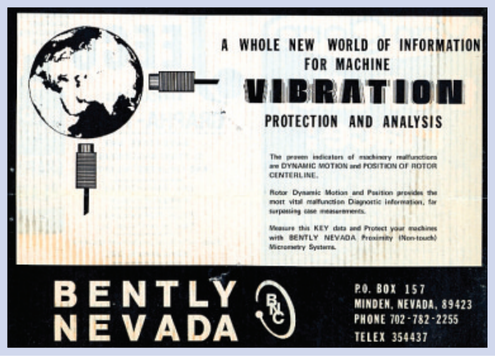
1963

1964

Beatles film "A Hard Day's Night." First rotor kit (RK-1) launched.

1965

3000 series transducers launched. "Proximitor" name coined as an abbreviation of PROXIMity monITOR. First field representative office opened in Ohio.



A WHOLE NEW WORLD OF INFORMATION
FOR MACHINE
VIBRATION
PROTECTION AND ANALYSIS

The proven indicators of machinery malfunctions are DYNAMIC MOTION and POSITION OF ROTOR CENTERLINE.

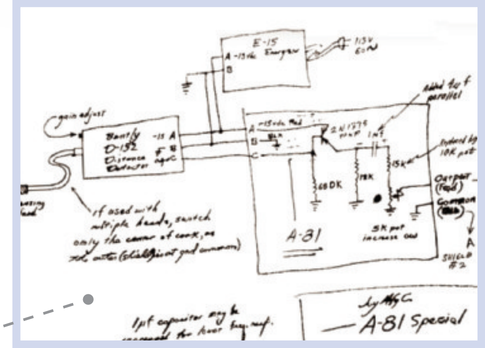
Rotor Dynamic Motion and Position provides the most vital malfunction Diagnostic information, far surpassing case measurements.

Measure this KEY data and Protect your machines with BENTLY NEVADA Proximity (Non-touch) Micrometry Systems.

BENTLY
NEVADA

P.O. BOX 157
MINDEN, NEVADA, 89423
PHONE 702-782-2255
TELEX 354437

HAND-DRAWN SYSTEM DIAGRAM FOR "A-81 SPECIAL" MONITOR


E-15
A -15vdc Energizer
B
115V
60~
gain adjust
Bently
D-152
Distance
Detector
-15 A
B
C
A
B
C
2N1375
PNP
1mf
added for parallel
replaced by 10K pot
15K
18K
680K
Output (Red)
Common (Blk)
A
Shield #2
A-81
5K pot
if used with multiple heads, switch only the center of each
A-81 Special

ADVERTISEMENT, CIRCA 1968 (NOTE DEPICTION OF XY PROBE PAIR AND USE OF FAMILIAR SHAFT ORBIT DESIGN AS COMPANY SYMBOL)

STRATEGIC DECISIONS

Building entire monitoring systems, rather than just transducer systems

Offering customer training

"Following the customer" to establish a distributed network of local sales & services employees.

1966

Japan launched Bullet Train. BNC entered monitor production. TK-3 "wobbulator" introduced for instrument loop checking and calibration verification.

1967

First heart transplant. Standardized 5000 series monitors launched. Beginning of the systems focus.

1968

"Wherever sales are available, service will also be available." New office opened in Louisiana.

1969

Neil Armstrong first man on the moon. First international BNC office opened in the Netherlands. First customer training class at the airport facility. Course focused on installation & calibration of transducer systems.

1970s

"Protecting Your Machinery"

During this decade, Bently's focus was to grow the core business and to become machinery diagnostic experts – not just machinery data collection experts. He increased employee count from 200 in 1970 up to 1000 in 1979. Main industries served continued to be OEMs and hydrocarbon processing industries (HPI), with a deliberate entry into protection systems for power generation. Product line additions included seismic transducers, bearing temperature monitors, and first steps to digital monitoring systems. Sales channels shifted from mostly representatives to mostly factory-direct sales force. The total number of field offices reached 24, with half in the USA and half in various international locations.

1970

Aswan High Dam completed. American Petroleum Institute (API) adopted proximity transducers for acceptance testing (API 617). First dual probe system delivered to large heavy duty gas turbine installation. 1700 series monitor introduced.

1971

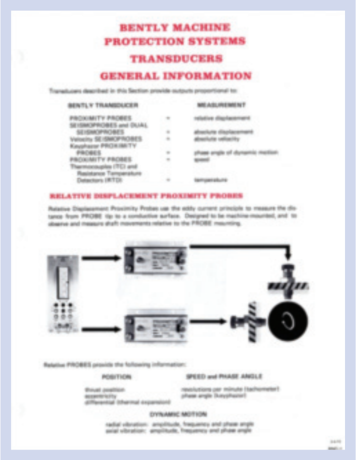
Deliberate entry to power generation segment.

1972

First Turbine Supervisory Instrumentation (TSI) offering via 7000 series system. Proximity transducers were recognized as an improvement over old "shaft-rider" systems.

1974

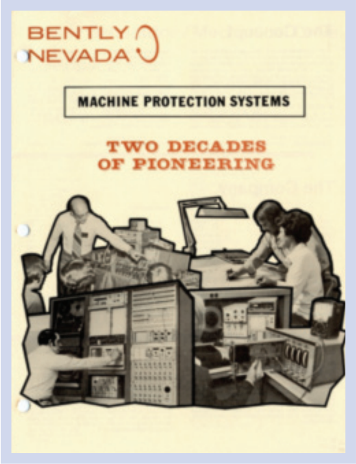
Terracotta Army discovered in China. 7200 series monitors launched.



BENTLY MACHINE
PROTECTION SYSTEMS
TRANSDUCERS
GENERAL INFORMATION

RELATIVE DISPLACEMENT PROXIMITY PROBES

MACHINERY PROTECTION SYSTEMS PORTFOLIO


BENTLY NEVADA
MACHINE PROTECTION SYSTEMS
TWO DECADES OF PIONEERING

ADVERTISING FOCUSED ON MACHINERY PROTECTION

DON'T JUST BUY API 670-
BUY FALSE TRIP PROTECTION
RVXY 2 from BENTLY NEVADA

AVOID FALSE TRIPS AND COMPLY WITH API-670

1975

Microsoft founded. 7200 series transducers launched; first software system. 9000 series monitors introduced.

1976

200,000th probe shipped. API 670 1st edition adopted by industry. Airport facility destroyed by fire.

1977

BNC adopted MRP and CRP programs.

1978

Mechanical Engineering Services (MES) launched. Would later become known as Machinery Diagnostic Services (MDS).

STRATEGIC DECISIONS

Focusing on the Power Generation industry as well as Oil & Gas.

Treating the destruction of the BNC airport facility as an opportunity to start over with improved resources planning processes (Class A, MRP2, Resource Planning Organization).

1980s

"Protecting and *Managing* Your Machinery"

Turbomachinery OEMs, Oil & Gas (hydrocarbon processing and offshore platforms) and Power Generation remained the core industries served during this decade. BNC moved beyond probes and monitors to include online Condition Monitoring (CM) software. Basic research at BRDRC enhanced the company's understanding of machinery behavior. The company grew from 1000 employees in 1980 to 1250 by 1989. The product line expanded to include API 670-compliant systems, ADRE, DDM/TDM software, custom products, and early portable data collectors. Sales channels continued to migrate away from representatives to factory-direct sales force. Total field offices exceeded 50 by 1989 with just over 30 being located internationally.

the Orbit

Premier Edition

published by Bently Nevada Corporation

summer 1980

BENTLY NEVADA INTRODUCES ADRE

FIRST ORBIT EDITION LAUNCHED THE NEW ADRE PRODUCT.

1980

ORBIT magazine launched. ADRE launched. Custom Products department introduced.

1981

Personal computers (PCs) introduced by IBM. 250th TSI system installed.

1982

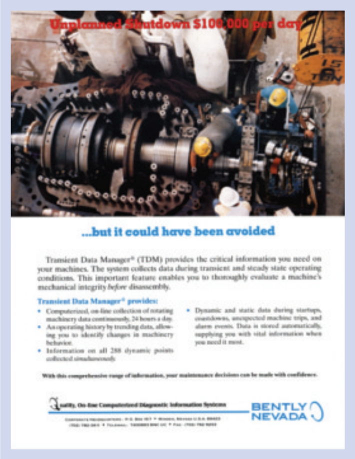
BRDRC formed to contribute to the field of rotordynamics knowledge and to advance the technology of electronic instrumentation for monitoring the mechanical performance of rotating machinery. Computerized Smart Monitor launched to integrate protection & management for first time.

1983

Data Manager software introduced.

1984

"Turnkey" Design & Installation Services (D&IS) launched to increase scope and expand TSI retrofits. First portable data collector introduced.


Unplanned Shutdown $100,000 per day

...but it could have been avoided

Transient Data Manager* (TDM) provides the critical information you need on your machines. The system collects data during transient and steady state operating conditions. This important feature enables you to thoroughly evaluate a machine's mechanical integrity *before* disassembly.

Transient Data Manager* provides:

- Computerized, on-line collection of rotating machinery data continuously, 24 hours a day.
- An operating history by trending data, allowing you to identify changes in machinery behavior.
- Information on all 288 dynamic points collected simultaneously.
- Dynamic and static data during startups, coastdowns, unexpected machine trips, and alarm events. Data is stored automatically, supplying you with vital information when you need it most.

With this comprehensive range of information, your maintenance decisions can be made with confidence.

Quality, On-line Computerized Diagnostic Information Systems

BENTLY NEVADA

ADVERTISING FOCUSED ON IMPROVING MACHINERY MANAGEMENT BY EFFECTIVELY EMPLOYING CONDITION MONITORING.

STRATEGIC DECISIONS

Leveraging experience with portable test kits to develop the Automated Diagnostics for Rotating Equipment (ADRE) product.

Starting Bently Rotor Dynamics Research Corporation (BRDRC).

1986

Mir space station launched. Dynamic Data Manager (DDM) introduced.

1987

DNA evidence first used in criminal conviction. Transient Data Manager (TDM) launched.

1988

3300 Series Monitors launched.

1989

Berlin Wall opened. 1,000,000th Bently Nevada transducer sold.

THE PATH TO SUCCESS FOR ANY BUSINESS IS TO MAKE EFFECTIVE STRATEGIC DECISIONS TO "DO THE RIGHT THINGS."

1990s

“Protecting and Managing *All* Your Machinery”

Bently’s goal was to remain focused on turbomachinery OEMs, power generation and hydrocarbon processing, and to expand into more general industrial facilities as well. The Trendmaster 2000 system was designed to accommodate monitoring needs where a permanently installed scanning system was appropriate. First performance monitoring software was added to the line. Sales channels expanded to a total of 80 offices in 42 countries, using factory direct sales force wherever possible.

STRATEGIC DECISIONS

Combining formerly non-compatible BNC software applications into one system (System 1 platform).

1990

Hubble Space Telescope launched. Trendmaster 2000 introduced. 3300 probe series launched. First generation “expert system” developed.

1991

Otzi the Iceman discovered in the Alps. D&IS sales exceeded $3 million.

1992

DDM2/TDM2 SW debuts. 2201 monitors launched.

1994

Chunnel opened between Britain & France. 1800 and 990 transmitters; 3500 monitoring system introduced.

1998

Performance Manager 2000 launched. Initial concepts for System 1 software discussed.

1999

Euro currency adopted. System 1 software developed with updated portable data collector. ARC advisory Group originated the term “Plant Asset Management” to describe systems specifically intended to enable the full scope of asset management functions in a plant (Reference 1).

When it comes to data collection, your safety is our main concern.
CAUTION
Trendmaster®2000
BENTLY NEVADA

PERMANENTLY INSTALLED SCANNING SYSTEMS ENHANCE PERSONNEL SAFETY.

2000s

Plant Asset Management (PAM)

In the early 2000s, Bently's strategy was to expand PAM offerings within the core business, and also with "new" verticals such as metals & mining, pulp & paper, water & wastewater. The product line added increased emphasis on thermodynamic performance monitoring. After acquisition by GE, sales channels were still factory direct where possible, with Bently Nevada specialists integrating with generalists within the broader GE organization.

Orbit
Third Quarter 2001 • Volume 22 • Number 3
SYSTEM 1
MORE THAN JUST MACHINERY
Plant Asset Management
Snapshot FAQs
Oil Analysis Lab
Pressurized Bearing Success
SYSTEM 1

2001 ORBIT ISSUE FOCUSED ON PLANT ASSET MANAGEMENT

2000

Human genome decoded. Bently constructed a new headquarters facility in Minden to take the place of several separate buildings.

2001

BNC moved into the new facility in Minden, USA. ARC report named BNC as the industry leader in the Plant Asset Management (PAM) category (Reference 2).

2002

GE acquired BNC. [See "Celebrating Ten Years with GE" on page 6 of this issue – Editor]

STRATEGIC DECISIONS

Selling Bently Nevada Corporation to the General Electric Company

Summary

Bently's key strategic decisions, made over five decades, continue to anchor the Bently Nevada Asset Condition Monitoring product line within GE. We are still focused on turbomachinery OEMs, power generation and hydrocarbon processing (oil & gas) industries, and continue to expand our plant wide condition monitoring capabilities. ■

References

1. Orbit Vol. 22 No. 3, Third Quarter 2001, Sabin, Steve & Law, Brad, "System 1 – What it is, what it does, how it fits."
2. Plant Asset Management and Condition Monitoring Worldwide Outlook, Market Analysis and Forecast through 2005, published May 2001 by ARC Advisory Group, Dedham, MA (www.arcweb.com)

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FUNCTIONAL SAFETY CERTIFICATION FOR RECIPROCATING COMPRESSOR MONITORING SYSTEMS

TYPICAL 4-THROW COMPRESSOR - GE OIL & GAS MODEL 4HE

Joseph K. Taylor
Bently Nevada Product Manager
josephk.taylor@ge.com

ACROSS TODAY'S GLOBAL OIL & GAS INDUSTRY, controls and instrumentation engineers are applying the process safety, risk assessment and reduction methodologies of IEC 61511, "Functional Safety – Safety Instrumented Systems for the Process Industry." IEC 61511 has become the acknowledged global reference standard for Functional Safety in the process industries. It is the basis for the European harmonized standard, EN 61511, and the U.S. counterpart, ANSI/ISA SP84.01, was closely harmonized with IEC 61511 in 2004.

The methods described in these standards are applicable to a wide variety of processes. Examples include; gas and liquid compression trains, hydrocarbon separation and reaction vessels, storage vessels, and many other processes as well as the rotating and reciprocating machinery that is used in these processes. A common result of a safety and risk assessment is identification of the need to reduce risk by application of a safety system that is independent of the process control system and can automatically bring the process to a safe state before a particular hazardous event occurs – even when the control system cannot. Safety systems that are applied in this manner typically consist of sensors, logic solvers, and final elements in any combination. Such a system is termed a Safety Instrumented System, (SIS).

A significant concern for a process engineer specifying a SIS is simply this. How do you know it will be available to fulfill its function at that critical instant when it is needed? Safety and protective systems have, of course, been in use long before development of today's Functional Safety standards. Proven-in-use and in-house evaluations are long-accepted approaches to qualify a protective or safety system. But over the past decade, partially in response to compliance and regulatory requirements, users are more often requesting certification of instrumentation used in Safety Instrumented Systems.

IEC 61508, "Functional safety of electrical/electronic/programmable electronic safety-related systems", describes procedures and methods that are used to evaluate and qualify safety related electronic instrumentation as well as the design and development and sustaining of such products by the instrumentation OEM. IEC 61508 is the primary basis for third-party certification of instrumentation used in a Safety Instrumented System.

Safety Integrity Level

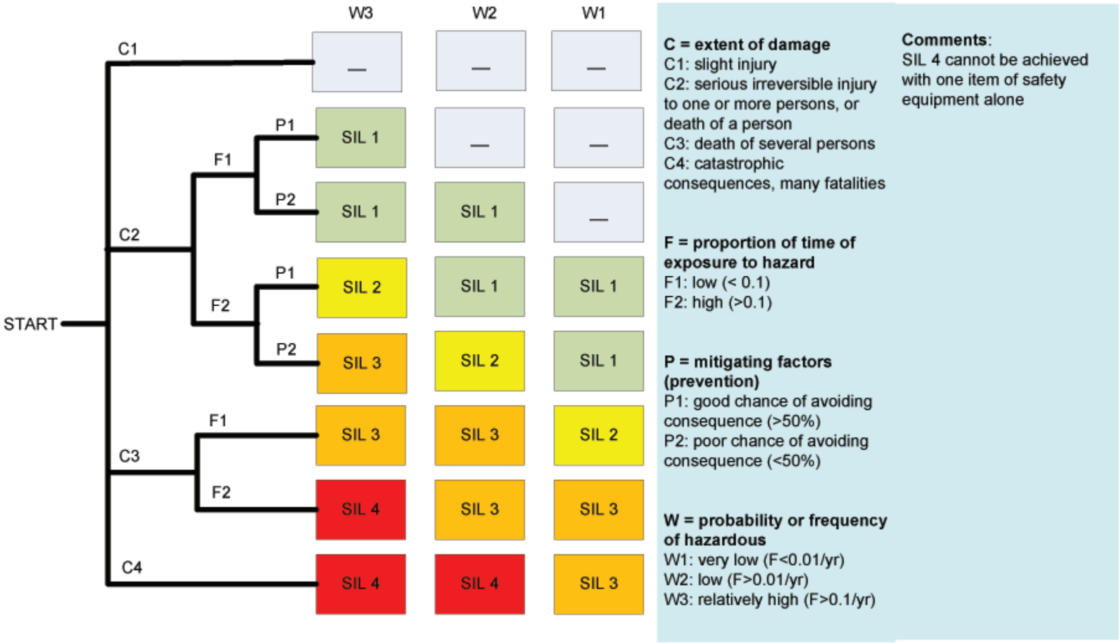
Safety Integrity Level (SIL) is a widely encountered functional safety concept. A thorough explanation of SIL and the process of defining SIL are beyond the scope of this article but we can describe the meaning of product certification to Safety Integrity Levels. In simple terms there are four SIL levels defined in IEC 61508/61511 that correspond to required levels of risk reduction, with SIL 4 being the highest risk category and requiring the greatest risk reduction (Figure 1).

Demand Mode	
Risk Reduction Factor	**SIL Safety Integrity Level**
100000 to 10000	SIL 4
10000 to 1000	SIL 3
1000 to 100	SIL 2
100 to 10	SIL 1

FIGURE 1: This table lists the magnitude of risk reduction that is required for each SIL level.

The SIL level is assessed for a plant process by a safety and risk analysis that considers potential hazards and their impact on personnel safety and safety of the environment, (Figure 2).

For the most significant identified hazards, mitigation plans are created that may include installation of a Safety Instrumented System. The SIS must be treated as a complete loop from detection of the hazard (measurement sensors) to the analysis of the measurements (a 3500 series monitor in this instance), to an Electronic Shutdown Device (the logic solver) to a final element that brings the process to the defined safe state (trip valve). In the process industries, this chain of functional components is sometimes referred to as "pipe to pipe." The SIS is expected to provide risk reduction appropriate for the SIL level. One way that is established is by examining the nature of the hazardous event.


W3
W2
W1
C1
—
—
—
P1
F1
SIL 1
—
—
P2
SIL 1
SIL 1
—
C2
P1
SIL 2
SIL 1
SIL 1
START
F2
P2
SIL 3
SIL 2
SIL 1
F1
SIL 3
SIL 3
SIL 2
C3
F2
SIL 4
SIL 3
SIL 3
C4
SIL 4
SIL 4
SIL 3

C = extent of damage
C1: slight injury
C2: serious irreversible injury to one or more persons, or death of a person
C3: death of several persons
C4: catastrophic consequences, many fatalities

F = proportion of time of exposure to hazard
F1: low (< 0.1)
F2: high (>0.1)

P = mitigating factors (prevention)
P1: good chance of avoiding consequence (>50%)
P2: poor chance of avoiding consequence (<50%)

W = probability or frequency of hazardous
W1: very low (F<0.01/yr)
W2: low (F>0.01/yr)
W3: relatively high (F>0.1/yr)

Comments:
SIL 4 cannot be achieved with one item of safety equipment alone

FIGURE 2: Example risk graph for personnel safety

Demand Mode Operation	
Safety Integrity Level	Average Probability of Failure on Demand
1	$\geq 10^{-2}$ to $< 10^{-1}$
2	$\geq 10^{-3}$ to $< 10^{-2}$
3	$\geq 10^{-4}$ to $< 10^{-3}$
4	$\geq 10^{-5}$ to $< 10^{-4}$

FIGURE 3: Required PFD_{AVG} to satisfy the four SIL levels.

Safe Failure Fraction		Hardware Fault Tolerance		
Type A Device	Type B Device	N = 0	N = 1	N = 2
—	0% to < 60%	—	SIL 1	SIL 2
0% to < 60%	60% to < 90%	SIL 1	SIL 2	SIL 3
60% to < 90%	90% to < 99%	SIL 2	SIL 3	SIL 4
≥90%	≥99%	SIL 3	SIL 4	SIL 4

FIGURE 4: HFT for 0, 1, or 2 faults, and SFF values for Type A and B devices.

Demand Mode

The likelihood of occurrence of the hazard can be categorized as being either continuous or discrete. Many hazardous events, such as overspeed or liberation of parts in a reciprocating compressor, are discrete events so a SIS that is intended to protect against them needs to have a measure of availability relative to the likelihood of occurrence of the hazard. “Demand Mode” is the term used for a SIS that is protecting against a discrete hazardous event and, in practice, is always identified as either “high” or “low” demand mode. Low demand mode is when the frequency of demand made on the safety system is not more than once per year and no greater than twice the proof test interval. The key criteria used to measure the availability on demand for a demand mode SIS is the “average probability of failure on demand” or PFD_{AVG}. Each component in the pipe to pipe safety loop will have its own PFD_{AVG}. PFD_{AVG} limits for each SIL level are shown in Figure 3. The complete pipe to pipe loop consisting of all the individual components must have a total PFD_{AVG} within the limits.

Calculation of PFD_{AVG} is a topic in itself. Key factors included in the evaluation, other than the failure modes and diagnostic capability of the device, are Mean Time To Restore (MTTR) and the Proof Test Interval (PTI). For end users this means that the supplier of the certified instrument is establishing an expectation of the time needed to restore the device to operation after a failure and the time interval between some form of verification test of the instrument. Both attributes will influence decisions on spare part inventory and maintenance planning.

Hardware Fault Tolerance (HFT) & Safe Failure Fraction (SFF)

In addition to PFD_{AVG}, there are other criteria that a product must meet to be certified for use in a particular SIS application. Examples of these are HFT and SFF. HFT and SFF have limits which depend on device type and SIL (Figure 4). Type A devices are “simple” devices, generally sensors, and Type B devices are “complex,” for example a 3500 series monitor.

Functional Safety is concerned with safety of personnel and the environment but the methods can be applied to protection against economic loss when additional measures are taken. System architecture design incorporating voting methods such as 1-out-of-1 (1oo1), 1oo2, 2oo2, 2oo3 etc., are important design choices to implement reliable protection and safety systems and, just as importantly, to protect against economic loss that can be caused by spurious shutdowns. SIL certified products will specify the redundancy configuration necessary to comply with its conditions of use as a Functional Safety system.

IN SIMPLE TERMS THERE ARE FOUR SIL LEVELS DEFINED IN IEC 61508/61511 THAT CORRESPOND TO REQUIRED LEVELS OF RISK REDUCTION, WITH SIL 4 BEING THE HIGHEST RISK CATEGORY AND REQUIRING THE **GREATEST** RISK REDUCTION.

RECOMMENDATIONS

The following recommendations are provided for a user or purchaser of a SIL certified demand mode product:

SIL certified product offers a number of benefits:

- The SIL statistics are calculated by an independent 3rd party.
- SIL statistics and additional information are available in the 3rd party test report.
- Certification to IEC 61508 provides assurance that the instrument OEM has stringent design practices and management of design changes.

Look for the SIL level that the instrument is rated for. All instrumentation in the loop must be rated for the target SIL or qualified through in-house or proven in use experience and analysis.

Consider the demand mode rating for the certified product and how it matches your assessment of process hazards.

Review both the SIL certificate and the certification test report. The two should not be used independently. Conditions of use may apply for SIL certified products and these may not be clear if you only look at the certificate.

A loop PFD_{AVG} budget analysis must be performed.

Understand the MTTR and the Proof Test Interval and what it means for your maintenance team and operation.

Recognize that certain aspects of SIL certification, and also just reliable interoperability, depend on the self-diagnostics of the overall SIS. For example, interconnecting sensors from one supplier with monitors from another supplier may not be as simple as it can appear.

Bently Nevada* machinery protection systems have been in use for more than 40 years and are an industry standard for API 670 and API 618 applications. So for many customers, our systems already meet the proven-in-use test. However, since 2002 we have offered Functional Safety (SIL) certified safety instrumented functions consisting of sensors and certain modules in our 3500 Machinery Protection System Product Line.

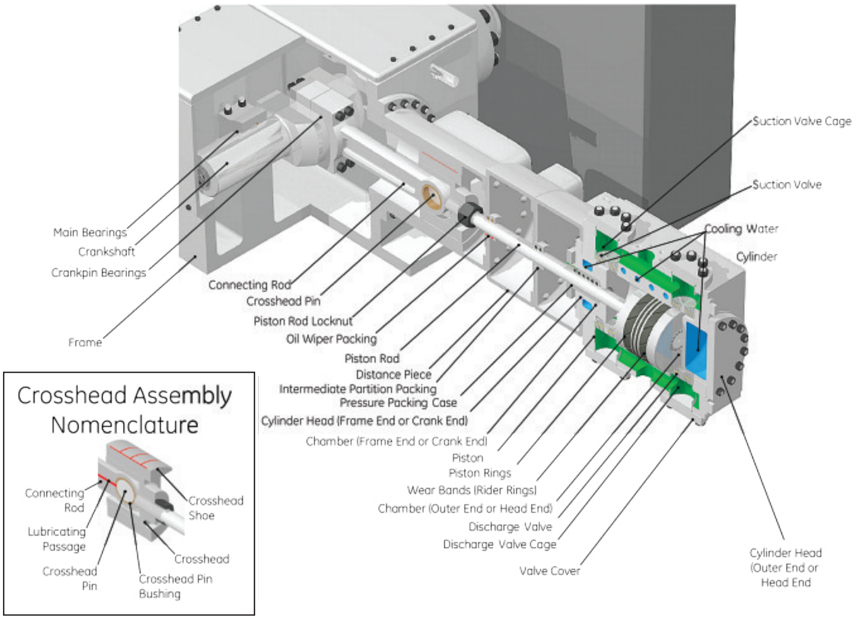

Suction Valve Cage
Suction Valve
Cooling Water
Cylinder
Main Bearings
Crankshaft
Crankpin Bearings
Frame
Connecting Rod
Crosshead Pin
Piston Rod Locknut
Oil Wiper Packing
Piston Rod
Distance Piece
Intermediate Partition Packing
Pressure Packing Case
Cylinder Head (Frame End or Crank End)
Chamber (Frame End or Crank End)
Piston
Piston Rings
Wear Bands (Rider Rings)
Chamber (Outer End or Head End)
Discharge Valve
Discharge Valve Cage
Valve Cover
Cylinder Head (Outer End or Head End
Crosshead Assembly Nomenclature
Connecting Rod
Crosshead Shoe
Lubricating Passage
Crosshead
Crosshead Pin
Crosshead Pin Bushing

FIGURE 5: Key components and nomenclature in a typical reciprocating compressor throw.

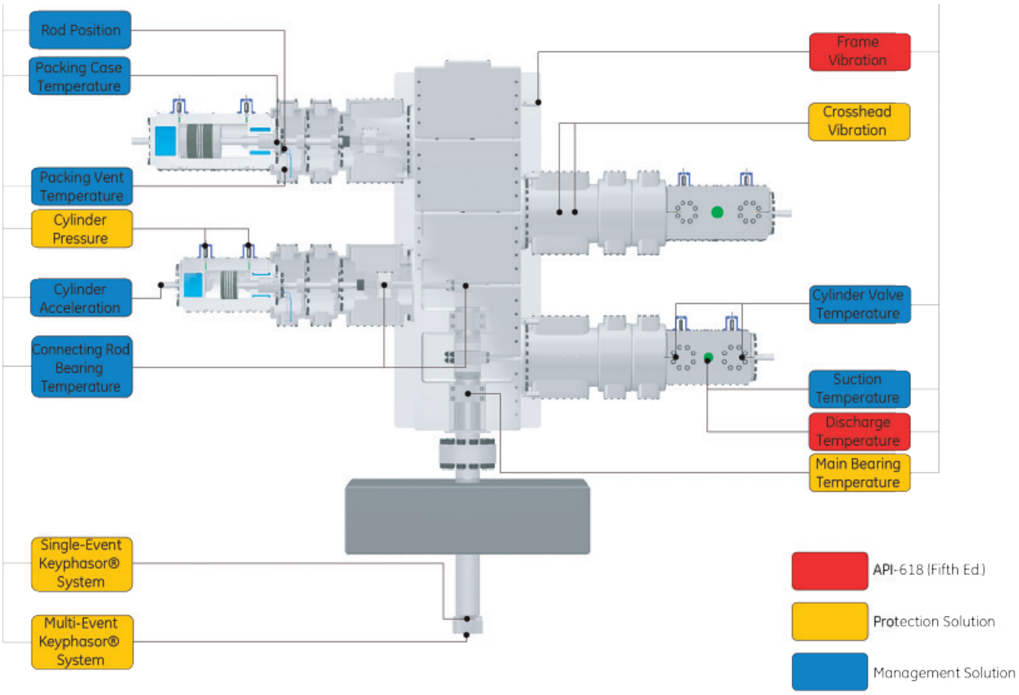

Rod Position
Packing Case Temperature
Packing Vent Temperature
Cylinder Pressure
Cylinder Acceleration
Connecting Rod Bearing Temperature
Single-Event Keyphasor® System
Multi-Event Keyphasor® System
Frame Vibration
Crosshead Vibration
Cylinder Valve Temperature
Suction Temperature
Discharge Temperature
Main Bearing Temperature
🟥 API-618 (Fifth Ed.)
🟨 Protection Solution
🟦 Management Solution

FIGURE 6: Recommended measurements for reciprocating compressor monitoring.

PRODUCT	APPLICATION	CERTIFIED FOR USE IN SAFETY INTEGRITY LEVEL
3500/70 Impulse Velocity Monitor	Frame vibration (1) (2) Crosshead acceleration(2) Cylinder vibration	SIL 2
3500/72 Rod Position Monitor	Dual or single sensor rod position Rod drop Hyper compressor plunger position(2)	SIL 2
3500/77 Cylinder Pressure Monitor	Suction and discharge pressure Min/max pressure(2) Compression ratio Combined Rod load(2) Rod load reversal	SIL 2
3500/25 Keyphasor* Module	Keyphasor and crankshaft angle phase reference for measurements made in the crankshaft angle domain.	SIL 2
3500/33 16-Channel Relay Module	Logic programmable relay contact output to ESD or final element.	SIL 2
3500/32 4-Channel Relay Module		SIL 2
3500/60 6-Channel Temperature Monitor	Temperature: Suction and discharge(1) (2) gas. Suction and discharge valves Packing case Crosshead shoe Main bearings(2)	SIL 1 (SIL 2 PENDING)
3500/61 6-Channel Temperature Monitor		SIL 1 (SIL 2 PENDING)
3500/65 16-Channel Temperature		SIL 2 PENDING
330180 3300XL 8 mm Proximity Sensor System	Rod position/drop Hyper Compressor plunger position Phase/crank shaft angle reference sensor	SIL 2
330780 3300XL 11 mm Proximity Sensor System		SIL 2
190501 Velomitor CT	Frame vibration sensor	SIL 2
350500 Velomitor		SIL 2
330400 Accelerometer	Crosshead acceleration sensor	SIL 2
330425 Accelerometer		SIL 2
165855 Cylinder Pressure Sensor	Cylinder pressure	SIL 2

(1) API 618 recommends Frame Vibration and Discharge Gas Temperature for auto-shutdown machinery protection.
(2) In addition to the API 618 protection measurements we recommend Crosshead Acceleration, Main Bearing Temperature, Cylinder Pressure, Combined Rod Load, and for reciprocating Hyper-Compressors: Hyper Plunger Position.

FIGURE 7: SIL certifications for Bently Nevada reciprocating compressor monitoring system components

> SIL certified products will specify the redundancy configuration necessary to comply with its conditions of use as a Functional Safety system.

Functional Safety Certification for Reciprocating Compressor Protection and Monitoring Systems

We are continuously enhancing our 3500 Machinery Protection System and we now offer Functional Safety certifications for our reciprocating compressor protection and monitoring product line (Figures 5 & 6).

A full suite of certified products is available, including the sensor, 3500 monitor, and 3500 relay output to the Electronic Shutdown Device (ESD) or final element. A critical aspect of a safety instrumented function is that it is a loop, not an isolated component. As listed in Figure 7, we offer a complete set of Functional Safety certified products for reciprocating compressor protection and condition monitoring loops from sensor to relay contact output.

Figures 8 & 9 show examples of the Functional Safety (FS) labels that are used on certified monitor modules. ■

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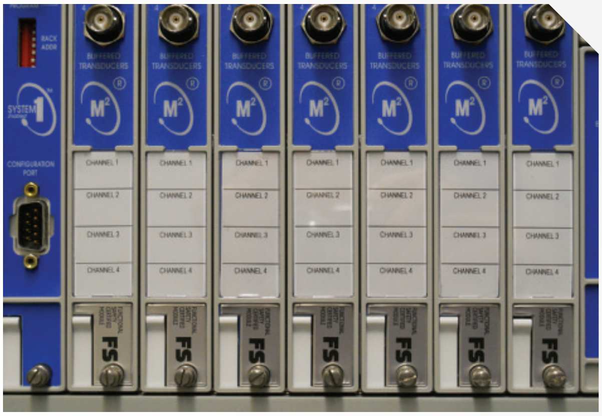

FIGURE 8: FS labels are located on the lower part of the faceplate for each certified module.

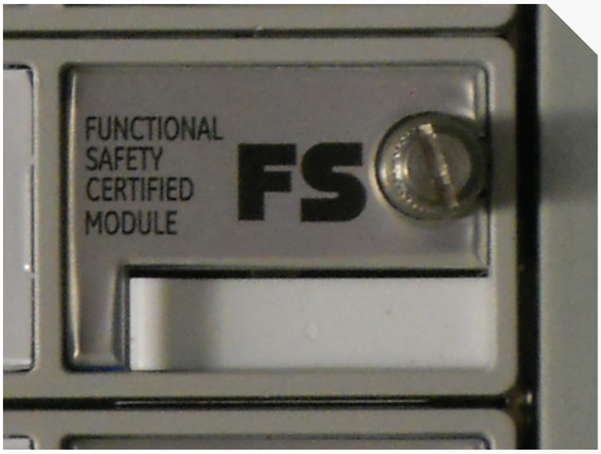

FIGURE 9: Close-up view of one of the certification labels.

PART NUMBERS AND OPTIONS

Gary B. Swift
Orbit Editor
gary.swift@ge.com

EVERY BENTLY NEVADA* PRODUCT IS IDENTIFIED BY A UNIQUE PART NUMBER. The first portion of the part number describes major characteristics of the component, while the "dash options" (separated by hyphens) describe specific features for the component.

As shown in Figure 1, the letters A, B, C, D, and E refer to five categories of available options for this generic part number example, and the XX indicates that a two-digit number will appear in each dash option block.

Different components have different numbers of option categories. There are not always five possible dash options as shown here. Also, some components have options that use 3-digit numbers rather than 2-digit numbers. 3-digit option categories are identified as **XXX** rather than **XX.**

Description of the various part numbers and options for any component are listed in Specifications and Ordering Information documents, which are often called "datasheets."

PART NUMBER	– AXX – BXX – CXX – DXX – EXX
Part number identifies major characteristics of the component.	Options describe additional features that are selected for a specific application.

FIGURE 1: Part number structure

PART NUMBER –	AXX –	BXX –	CXX –	DXX –	EXX
330101 –	20 –	96 –	50 –	12 –	00
3300XL 8mm Proximity Probe, 3/8-24 UNF Thread, with no armor on probe cable.	Unthreaded Case Length 2.0 inches	Overal Case Length 9.6 inches	Total Length 5.0 metres (including probe cable)	ClickLoc* Connector, FluidLoc* Cable	No Agency Approval (not for use in Hazardous Areas)

FIGURE 2: Example of 8mm Proximity Probe with specified options

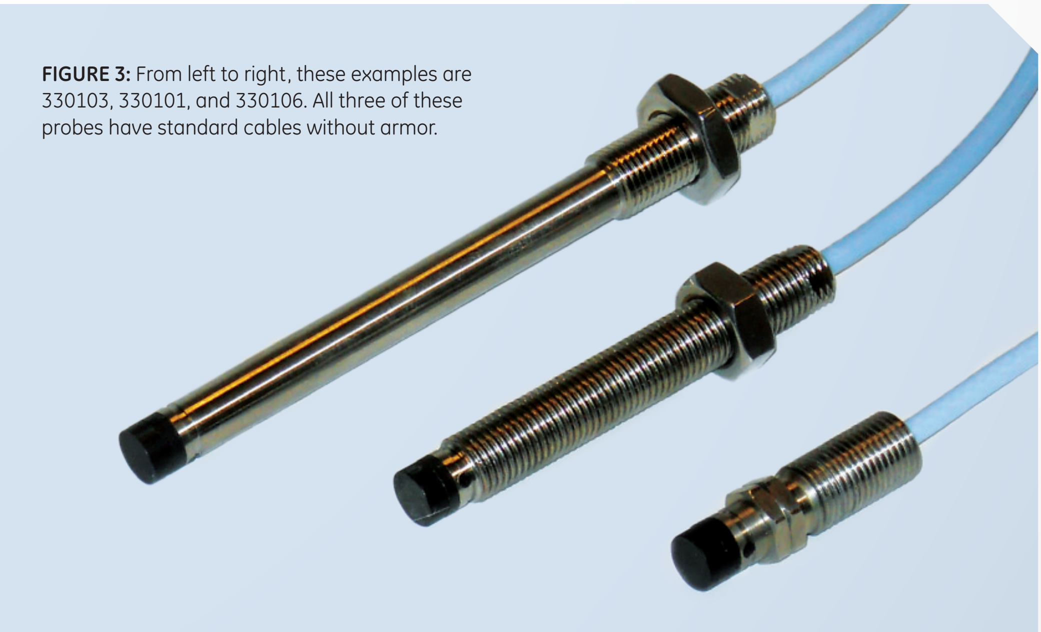

FIGURE 3: From left to right, these examples are 330103, 330101, and 330106. All three of these probes have standard cables without armor.

Proximity Transducer Example

The 3300 XL 8mm proximity system is commonly used for protection and condition monitoring of machinery with fluid film bearings. We will use components from this familiar system as examples throughout this mini-article.

In this example (Figure 2), the basic part number (330101) refers to a 3300 XL 8mm standard mount proximity probe with no armor on the probe cable and with 3/8-24 UNF (fine) threads on the probe case. Each of the five available options is defined by a two digit number, as listed here (Reference 1).

Ⓐ The value of 20 in the first option block indicates that the unthreaded length of the probe case is 2.0 inches.

Ⓑ The 96 in the second block stands for 9.6 inches of overall probe case length.

Ⓒ The 50 in the third block signifies a total electrical length of 5.0 meters for the probe and integral probe cable.

Ⓓ The 12 in the fourth block means that the probe includes a miniature coaxial ClickLoc* connector and a FluidLoc* cable.

Ⓔ Finally, the 00 in the fifth block indicates that no agency approvals are included with the probe, so it cannot be used in a Hazardous Area (with potentially combustible atmosphere).

Proximity Probe Part Numbers

For some products, such as the 3300 XL 8mm proximity probes described here, a variety of different characteristics are specified within the six-digit part number itself, and are independent of the available dash options. The datasheet for this probe family actually includes sixteen different part numbers - representing differences in the probe case, describing whether or not the probe cable is armored, and describing various versions of the probe that are designed for use in a high temperature environment. Three probe examples are shown in Figure 3.

- 330103 = 3300 XL 8mm Probe, M10x1 thread
- 330101 = 3300 XL 8 mm Probe, 3/8-24 UNF thread
- 330106 = 3300 XL 8 mm Reverse Mount Probe, M10x1 threads

Note: Reverse mount probes are typically installed in internally-threaded probe sleeves, which protect the cable as well as supporting the probe at its required monitoring location. In this design, the hexagonal nut is an integral part of the probe case, and is not a separate fastener. This type of probe is threaded cable-end first into its mounting hole during installation.

System Length

It is important to understand that the probe, the extension cable (if required for the specific installation) and Proximitor* Sensor make up a tuned resonant circuit. The system components are designed – and tested – to ensure that system accuracy will be within specification if the components are combined correctly. The total length option of the probe and of the extension cable must sum to equal the total length option of the Proximitor Sensor. Mismatched components may cause measurement errors of 20% or greater. The “lengths” of the components correspond to precise electrical specifications, so the actual physical lengths of probe cables and extension cables may be very slightly different from the labeled lengths in meters.

Example: Combining a 1 meter probe with an 8 meter extension cable requires that a 9 meter Proximitor sensor be used.

Extension Cable Part Numbers

Unlike the 3300 XL 8mm probe, which has 16 different basic part numbers, the associated extension cable only has two possible part numbers. The Extended Temperature Range (ETR) cable is part number 330190, while the standard cable is part number 330130. Both cable types have three option categories:

Ⓐ **CABLE LENGTH**: Extension cable length is always specified in meters, just as Total Length is always specified in meters in probe options.

Ⓑ **CABLE OPTIONS:** This option describes whether the cable is standard or FluidLoc* type, whether or not it has armor, and whether or not connector protector boots are already installed.

Ⓒ **AGENCY APPROVALS:** Just as with proximity probes, we can either select a cable that has NO Hazardous Area approvals, or one that has ALL available approvals. We cannot choose to have some approvals and not others.

Note: For a system that will be installed in a Hazardous Area, it is important to ensure that ALL of the system components have the required approvals.

Extension Cable Example

Using the datasheet, we can decode the meaning of the part number, 330130-080-02-00:

- 330130 = 3300 XL Standard Extension Cable
- 080 = Cable length of 8.0 meters
- 02 = Standard cable with connector protectors already installed
- 00 = No agency approvals (not allowed for use in Hazardous Areas)

Proximitor Sensor Part Numbers

The 3300 XL Proximitor Sensor has only one possible basic part number, 330180, and two option categories:

Ⓐ **TOTAL LENGTH & MOUNTING:** This option specifies both the total system length (always in meters) and the mounting method (DIN or Panel Mount) for the sensor.

Ⓑ **AGENCY APPROVALS:** Just as with proximity probes and extension cables, we can select a Proximitor Sensor that has NO Hazardous Area approvals, or one that has ALL available approvals. We cannot choose to have some approvals and not others.

Proximitor Sensor Example

Using the datasheet, we can decode the meaning of the part number, 330180-91-05:

- 330180 = 3300 XL Proximitor Sensor
- 91 = 9.0 meter total system length, with DIN rail mount
- 05 = Multiple agency approvals (OK for use in Hazardous Areas) ■

References

1. 3300 XL 8mm Proximity Transducer System, Specifications and Ordering Information, Part Number 141194-01.]

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SELECTING THE RIGHT SENSORS FOR YOUR MACHINE

A PRACTICAL GUIDE

Nate Littrell, P.E.
Bently Nevada Systems
Application Leader
nate.littrell@ge.com

IT'S A LANDMARK – You've finally gotten approval to instrument your machines to enhance your machinery reliability management program. This is a great place to be, but in some respects, it can be very challenging. The early stage of designing a vibration monitoring system requires knowledge of both the machinery and the technology used to detect vibration. This article provides guidance into the selection of Proximity systems, Accelerometers and Velocity vibration sensors by matching the fundamental machine characteristics with the correct sensor.

Selecting the proper sensor is the foundational decision that determines the successful function of a machinery management or protection system. There are two fundamental requirements for any sensor. First, it must be capable of detecting the behavior that is deemed of interest. Secondly, it must interface to the rest of the management system.

The eddy current proximity transducer is the recommended vibration monitoring system for most machines with fluid film bearings. These systems have a frequency response starting at 0 Hz and extending in to the 10 kHz range, allowing them to accommodate the important vibration data for nearly every machine. The eddy current probe also has no moving parts, which contributes to extraordinary reliability.

These probes are typically mounted directly to the bearing support and measure radial shaft motion and position of the shaft relative to the bearing. This measurement is sometimes called relative vibration to highlight that the measurement is relative to the shaft and bearing.

In addition to vibration, the proximity probe is able to measure the shaft's average radial position within the bearing housing or axial position relative to the thrust bearing. This is useful to diagnose alignment, shaft loading, and bearing wear issues. This measurement is a unique capability to this type of sensor and is of great use, not only to the diagnosis of the problem, but to enable a clear picture of the path to fix the problem.

Application of eddy current probes requires careful consideration of several factors. The required frequency response and expected magnitude of the vibration must be within the capability of the sensor. The eddy current probe is also sensitive to shaft material and surface finish. The standard product is calibrated to AISI 4140 steel and custom calibrations are available if needed. Special probes are also available for applications involving extreme temperatures & pressures, or requiring resistance to corrosive chemicals.

Bently Nevada
Asset Condition Monitoring
3300 XL 5/8mm PROXIMITOR® SENSOR
COMPATIBLE WITH ALL 5 & 8 mm
3300 AND 3300 XL PROBES
Bently Nevada
RELATIVE PROBE ASSEMBLY
CATALOG NUMBER
24701-28-05-04-02
25-049
MOD #

Accelerometers

An accelerometer is an inertially referenced (seismic) device, but one with essentially no moving parts. The sensor contains a piezoelectric crystal upon which a reference mass is mounted. As the sensor vibrates, the reference mass exerts a force on the crystal causing a charge to develop proportional to the force. This charge is converted and amplified to a voltage output proportional to acceleration.

Accelerometers typically have a broad frequency response, making them especially useful for high frequency measurements. Acceleration values also increase with frequency, which favors the acceleration unit of measurement. However, this same characteristic of physics limits the sensor's use at low frequencies because there is simply not enough acceleration to accurately measure.

Although seemingly easy to install, accelerometers are quite sensitive to the method of attachment and quality of mounting surface. This may not be a problem for mid frequency applications, but it becomes more critical as the desired measurement frequency increases. A disadvantage of the accelerometer is its sensitivity to noise, which can introduce spurious vibration to the signal. Also, due to the wide frequency range, it often requires filtering in the monitor. The accelerometer is not capable of measuring direct shaft motion or slow roll vibration, although it is very effective at measuring characteristic frequencies of rolling element bearings.

The 330400 and 330425 sensors are similar externally and in how they interface to other equipment. The difference is in their dynamic range and sensitivity. The 330425 can measure a larger range of acceleration. This is accomplished by using a lower sensitivity in order that the maximum signal stays within expected voltage limits. The associated monitor system design needs to know the expected range of vibration and choose the most sensitive transducer that will still cover the expected vibration limits. It is also important to include a safety factor such that the

TABLE 1 *lists representative examples of accelerometers from the Bently Nevada portfolio.*

PART NUMBER	TYPICAL APPLICATIONS	CHARACTERISTICS
330400 & 330425	Gearboxes, Reciprocating Compressors, General purpose, API 670	100 mV/g & 25 mV/g 50 & 75 g max 10 Hz to 15 kHz
330450 HTAS	Temperature to 400C Typically gas turbines	100 mV/g 80 G peak 15 Hz to 10 kHz
200150	Trendmaster TIM only General purpose	100 mV/g 25 g 0-pk 10 to 1000 Hz
200155	Trendmaster TIM only Low speed machinery	20 g 0-pk 1.5 Hz to 10 kHz
200157	Trendmaster TIM only Use for enveloping	25 g 0-pk 10 Hz to 10 kHz

sensor will still function normally in the event of machinery problems. It is undesirable for the sensor to go into a NOT OK state due to a foreseeable machinery malfunction.

Velocity Transducers

Velocity sensors may be of two basic designs. They can be solid state devices which are essentially accelerometers as described above, with the addition of an integration circuit. The Bently Nevada Velomitor* product line is an example of this type of sensor. Alternatively, the velocity sensors may be of an electromechanical design using a spring mounted coil that moves relative to a permanent magnet. With this design, as the sensor vibrates, a voltage is induced in the coil which is proportional to velocity.

The advantage of the integrating accelerometer design is the solid state construction and durability. The advantage of the moving coil design is that the signal is naturally in units of velocity, and – like a traditional dynamic microphone – the transducer does not require an external power supply. There is also an improved signal to noise ratio at low frequencies due to having no additional noise from an integration circuit. Frequency response of most velocity sensors is limited to one or two kHz, making them suitable for machinery with very low frequencies of interest.

TABLE 2 *lists representative examples of velocity sensors from the Bently Nevada portfolio.*

PART NUMBER	TYPICAL APPLICATIONS	INTERFACE NOTES	SCALE FACTOR FREQUENCY RANGE DYNAMIC RANGE
330505 Low frequency velocity	Low frequency equipment, hydro turbines	Interfaces with 3500/46M hydro monitor	
330500 Velomitor	General purpose velocity sensor	Interfaces with 3500/42M	3.94 mV//mm/s (100 mV/ins) 6 Hz to 2.5 kHz 1270 mm/s (50in/s) maximum
190501 Velomitor CT	Reciprocating Compressors, Low frequency equipment, Cooling Tower fans	Interfaces with 3500/42, & 1900 systems	3.94 mV//mm/s (100 mV/ins) 1.5 Hz to 1 kHz 2.5 in/s maximum
350900 HTVAS	High temperature areas up to 482 C, Gas Turbines		3.94 mV//mm/s (100 mV/ins) 25 Hz to 2 kHz 1270 mm/s (50in/s) maximum
330525 Velomitor XA	Velomitor with tapered pipe thread mount and different connector. NEMA 4X and IP 65 rating		3.94 mV//mm/s (100 mV/ins) 4.5 Hz to 2 kHz 1270 mm/s (50in/s) maximum
330530 Radiation resistant Velomitor	Nuclear Plants: Rated for up to 3 MRads of gamma radiation. BWR designs typically have distributed low level gamma radiation that need to be accommodated by sensors.		3.94 mV//mm/s (100 mV/ins) 4.5 Hz to 5 kHz 635 mm/s, 25 in/s
330750 & 330752 HTVS	High temperature up to 400 C	Contrast with HTVAS	5.7 mV/mm/s (145 mV/in/s) 20 Hz to 1 kHz 6 in/s maximum 0-pk

At frequency ranges up to a few kHz, it is up to the preference of the system designer whether to use a Velomitor or accelerometer. However for applications with higher frequency content, it is often necessary to use an accelerometer.

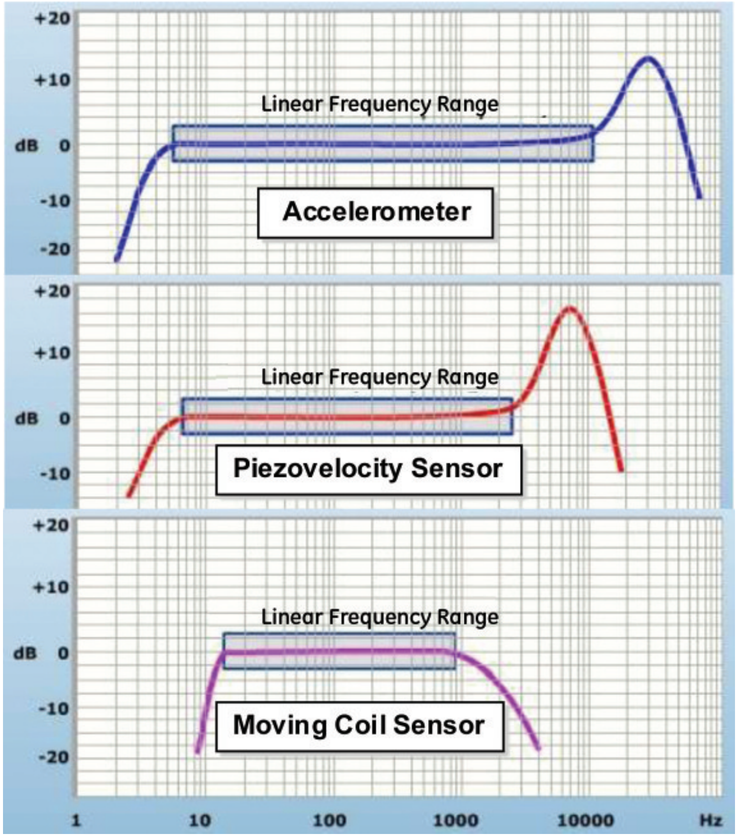
The Velomitor CT was developed specifically for low frequency application (particularly the large fans in forced-draft Cooling Towers, hence the CT designator). The frequency response of this sensor is from 1.5 Hz to 1 KHz. It is also robust in the typically moist atmosphere of cooling towers, with a specially designed conduit attachment point on the senor to protect the electrical connection. A caveat with this sensor is that high frequency components above 1 kHz (upper limit of sensor response) can reduce the dynamic range of the sensor.

The 330505 Low frequency velocity sensor is designed for applications requiring frequency response as low as 0.5 Hz. This sensor is typically used in hydroelectric power applications with slow moving machinery and subsynchronous vibration.

For high temperature applications such as aeroderivative gas turbines, there is the 350900 sensor, which is rated for use up to 482 C.

Figure 1 illustrates the relative frequency response of typical of velocity sensors and accelerometers.

FIGURE 1: Observe that the accelerometer and integrating accelerometer (piezovelocity sensor) both exhibit sensitivity peaks in the upper end of their frequency ranges. Although this peak produces non-linear measurements of high frequencies, this response can actually be used to advantage, as it can “magnify” very small levels of high-frequency vibration.



Machine Characteristics

The starting point to choose a sensor is knowledge of the machine. The failure modes and design details give insight to the required sensor type and performance specifications. Frequency range of interest defines the required response of the sensor.

BEARING TYPE

Generally, the transmissibility of and frequency range of characteristic vibration for Rolling Element Bearings (REB's) and fluid bearings are different. Transmissibility is a measure of the amount of motion that is transferred from the shaft to the bearing housing. REB's are stiffer and transmit more force directly to the bearing support. REB's also have frequency components, such as Ball Spin frequency, which are higher than rotating speed. This drives the tendency to use proximity probes on fluid bearings and accelerometers or Velomitors on machines with rolling element bearings. For machines with fluid bearings and soft supports, it may be advisable to use a shaft absolute measurement.

Typical Malfunctions

UNBALANCE

Balance problems manifest predominately as Synchronous (1X) vibration. The frequency response of the sensor must match the running speed of the machine. Eddy current probes are preferred for managing balance issues due to the accuracy of the phase measurement used for balancing. The eddy current probe measures naturally in units of displacement. Velocity and acceleration sensors must be phase corrected (90 and 180 degrees, respectively) in order to allow determination of a balance weight location. Generally, the phase measurement from seismic sensors is not as accurate as the eddy current probe.

MISALIGNMENT

Average shaft centerline position is the clearest indicator of an alignment problem. The eddy current proximity probe is the only sensor that can provide this measurement.

AXIAL THRUST CHANGE

Axial thrust measurement is a DC, or static, measurement rather than a waveform measurement. The eddy current proximity probe is the only sensor that can provide this measurement. Due to the severity of the damage from thrust failure and possibility that the probe may be damaged by thrust motion it is recommended that dual probes be used in a voting arrangement.

GEAR TOOTH WEAR

Gear mesh frequencies tend to be high, and problems with gear teeth manifest as small impact events exciting the natural frequency of the machine components. Accelerometers are commonly used on gearboxes to detect these high frequencies. Eddy current probes should also be used if the gearbox has fluid film bearings or supports significant thrust load.

Other machinery problems, such as rubs, rotor cracks, loose parts, cavitation, etc. all have their own detailed vibration characteristics. It is beyond the scope of this article to cover all possible machinery problems. The point is that any known or expected problems should be considered when selecting sensors for a specific application.

Shaft Absolute Measurement

In some cases it is necessary to measure both relative (Proximity probe observing the shaft) and absolute/seismic vibration. This is needed when both the motion of the shaft in the bearing and the motion of the bearing support structure are significant. The ratio of rotor motion relative to the bearing and bearing absolute motion is known as transmissibility.

As mentioned earlier, transmissibility is a key concept for evaluating the relative stiffness of the bearing to that of the support structure. A recommended practice is that shaft absolute measurements (i.e. the addition of seismic sensors) should be considered when the motion of the bearing support is more than 30% of the relative vibration level

Many large machines fall into this category. As an example, some large single shaft heavy duty gas turbines in power generation service have flexible bearing supports and the manufacturer outfits them with shaft absolute sensors as standard equipment.

Conclusion

This article is a starting point for the journey to complete machinery management. We have not discussed the topic of selecting the monitoring system, which is equally important to selecting the transducers. The main factors driving a choice between the three sensor types discussed are frequency response and transmissibility of the rotor/bearing/structural support system.

These factors combine with the knowledge we have of expected machinery malfunctions to guide us to a solution. In summary, eddy current proximity probes are usually the most appropriate choice for machinery with fluid bearings, where the rotor can move significantly within the clearance of the bearings. Accelerometers and velocity sensors are useful for measuring the movement of bearing supports and machine casings, and for monitoring the characteristic frequencies of rolling element bearings. ■

Reference

Orbit Vol. 29 No. 1, 2009. Littrell, Nate, “Application Considerations for Eddy-Current Proximity Probes.” This article includes a detailed discussion of proximity probe installation topics. It is available for download at the following link: http://www.ge-mcs.com/download/orbit-archives/1Q09_Prox_Probes.pdf

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HOW TO SET UP YOUR ADRE* FOR NON-STANDARD TRANSDUCERS

John W. Kingham
Field Application Engineer
john.kingham@ge.com

I WAS REALLY TEMPTED TO CALL THIS ARTICLE "HOW TO SET UP YOUR ADRE FOR 'ODDBALL' TRANSDUCERS" BUT I DIDN'T WANT ANYONE TO GET UPSET.

ODDBALL: Adjective (informal): peculiar, strange or unusual.

In reality, the ADRE system is so versatile that it can handle just about any transducer you want to throw at it. The only real requirements are that the transducer signal be between +25 V and -25V, or within the range of 4 to 20 mA.

For informational purposes, I am using Sxp software version 2.8, which is the latest version as the time of this writing (4th quarter of 2012). Most of this article is relevant all the way back to the initial release of the software, although it should be noted that with version 2.8 we made it easy to specify position measurements, such as axial position, commonly referred to by its protection parameter name, "thrust position."

ADRE 408
ADRE® 408 DSPi
DYNAMIC SIGNAL PROCESSING INSTRUMENT

NOW, LET'S HAVE SOME FUN

Our first transducer is going to be a torque sensor. I haven't used one of these in about 20 years, but let's not let that stop us. I have created a database on my computer without connecting to a 408, therefore, all I have are empty slots (Figure 1).

In order to make a measurement, I first need to define the card (or at least the channel). We have made it easy for you to change cards to be all proximity, all velocity, all acceleration, or all generic. To select sampling cards for empty slots, right-click on the card (or the individual channel, and select **Change To** from the shortcut menu. I am going to make the first slot a "generic dynamic (waveform)" card.

Now right-click on the new card and select **Configure** from the shortcut menu. We will head directly to the **Transducer** tab (Figure 3). The first channel will be highlighted. By default, it will probably indicate that the measurement type is Temperature. If you expand the drop down menu, you will see that Torque is already provided as an option in the list. As a point of reference, Frequency, Voltage, Force, Mass, Mass Flow, Power, Pressure, Volume, Volume Flow, Work, Head, MVAR and Angle are also available measurement types by default.

Once I have selected torque, I notice that the Units and Display Preference for units is in N*m pp (SI units of Newton-meters, peak to peak measurement), rather than the US customary units of lb*ft pk (Pound-foot, peak measurement) that I would prefer to see for my particular application (Figure 4).

If we expand the drop down box under Units, we will see several selections including "lb*ft." This is the one I want to use. The problem is, that once you select it, you'll notice that the display preference units will still be in N*m. Don't worry; we have that covered as well. Go to the main toolbar and select "Plots." From the drop down, select **Plot Preferences** and then select the **Units** tab. Scroll down to **Torque,** expand the drop down box under **Display Units** and select "lb*ft." Now, when you go back into your configuration screen, you will have all the proper units (Figure 5).

This is pretty good so far, but what if you have a transducer that isn't covered with our large inventory of predefined units? Off the top of my head, I can't think of a measurement that might be of interest that we haven't covered yet, so I am going to make one up. Let's measure a property called "Flieglers" after my 10th grade physics teacher.

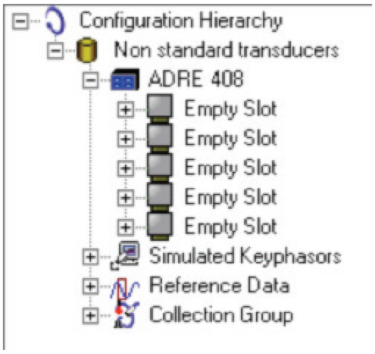

Configuration Hierarchy
Non standard transducers
ADRE 408
Empty Slot
Empty Slot
Empty Slot
Empty Slot
Empty Slot
Simulated Keyphasors
Reference Data
Collection Group

FIGURE 1: Example configuration hierarchy showing unspecified "empty slots."

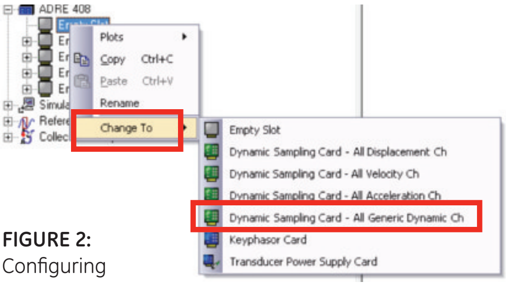

ADRE 408
Plots
Copy Ctrl+C
Paste Ctrl+V
Rename
Change To
Empty Slot
Dynamic Sampling Card - All Displacement Ch
Dynamic Sampling Card - All Velocity Ch
Dynamic Sampling Card - All Acceleration Ch
Dynamic Sampling Card - All Generic Dynamic Ch
Keyphasor Card
Transducer Power Supply Card

FIGURE 2: Configuring empty slots for required sampling cards

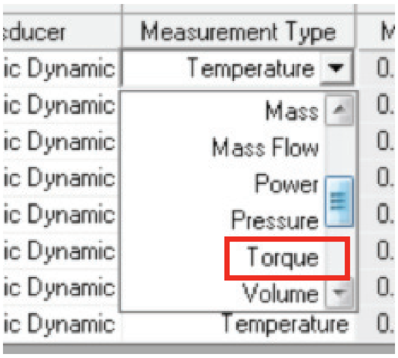
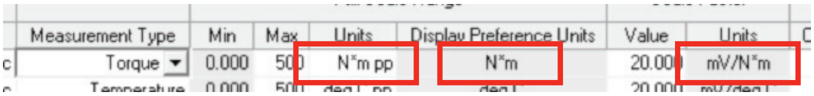
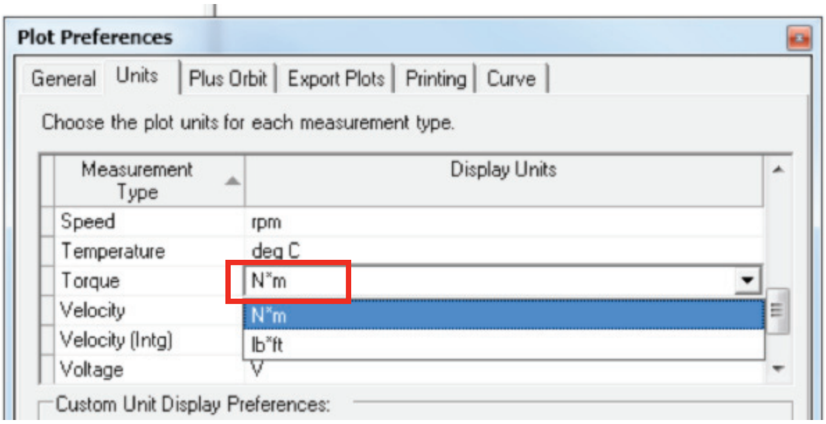

sducer
Measurement Type
ic Dynamic
Temperature
Mass
Mass Flow
Power
Pressure
Torque
Volume
Temperature

FIGURE 3: Specifying measurement type for the selected sampling card



Measurement Type	Min	Max	Units	Display Preference Units	Value	Units
Torque	0.000	500	N*m pp	N*m	20.000	mV/N*m

FIGURE 4: By default, SI measurement units are assigned.



Plot Preferences

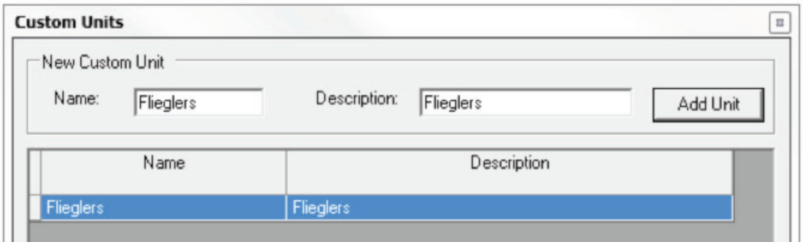
Choose the plot units for each measurement type.

Measurement Type	Display Units
Speed	rpm
Temperature	deg C
Torque	N*m
Velocity	
Velocity (Intg)	
Voltage	V

Custom Unit Display Preferences:

FIGURE 5: Preferred display units can be changed in Plot Preferences.

IN REALITY, THE ADRE SYSTEM IS SO VERSATILE THAT IT CAN HANDLE JUST ABOUT ANY TRANSDUCER YOU WANT TO THROW AT IT. THE ONLY REAL REQUIREMENTS ARE THAT THE TRANSDUCER SIGNAL BE BETWEEN +25 V AND -25V, OR WITHIN THE RANGE OF 4 TO 20 MA.



Custom Units

New Custom Unit

Name: Flieglers

Description: Flieglers

Name	Description
Flieglers	Flieglers

FIGURE 6: Custom Units dialog example.

Go back to the main toolbar, and select Tools, Custom Units. From here, a new Custom Units dialog box will open (Figure 6). We will type 'Flieglers' in the Name and Description boxes. Once I click **Add Unit,** the new custom unit will be shown in the table of available custom units.

So, now, how do we go about configuring the channel to record Flieglers? It's quite simple actually. Go back to your channel configuration screen—we will do channel 2, the one right below the Torque example. Again, go to the Transducer configuration tab. Once there, select a measurement type of Custom (Figure 7).

Once you have selected Custom as your measurement type, you will notice that the Units cell is blank. From that cell, select Flieglers from the dropdown menu (Figure 8). It will be your choice if you want this parameter in peak-to-peak, peak or rms measurement.

I hope that this helps to demystify the use of measurement types that are not already listed as default values in our Sxp software. See you the next time the KPH rolls around!

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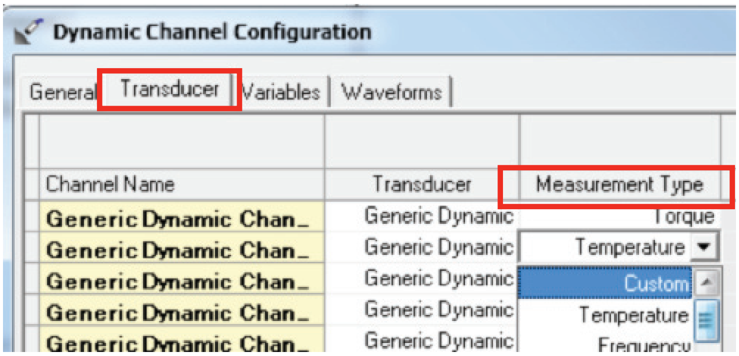
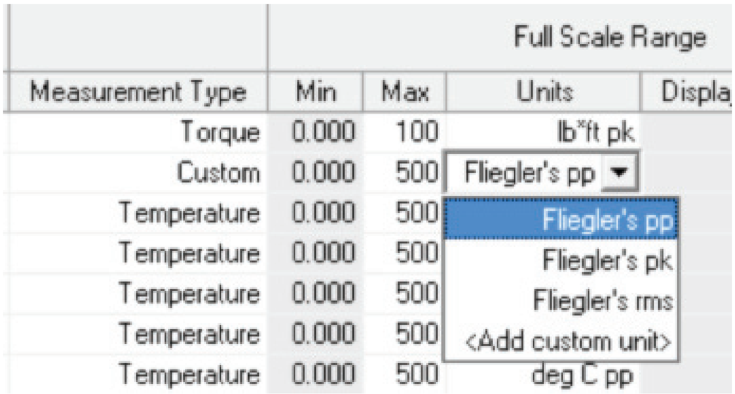


Channel Name	Transducer	Measurement Type
Generic Dynamic Chan…	Generic Dynamic	Torque
Generic Dynamic Chan…	Generic Dynamic	Temperature
Generic Dynamic Chan…	Generic Dynamic	Custom
Generic Dynamic Chan…	Generic Dynamic	Temperature
Generic Dynamic Chan…	Generic Dynamic	Frequency

FIGURE 7: Selecting Custom units in Transducer configuration tab



			Full Scale Range	
Measurement Type	Min	Max	Units	Displa
Torque	0.000	100	lb*ft pk	
Custom	0.000	500	Fliegler's pp	
Temperature	0.000	500	Fliegler's pp	
Temperature	0.000	500	Fliegler's pk	
Temperature	0.000	500	Fliegler's rms	
Temperature	0.000	500	<Add custom unit>	
Temperature	0.000	500	deg C pp	

FIGURE 8: Selecting units for custom measurement

MIGRATING YOUR LEGACY PORTABLE DATA COLLECTOR (PDC) TO SCOUT IS EASIER THAN YOU THINK!

Bob Craft
Bently Nevada Field
Application Engineer
Robert.Craft@ge.com

Walid El-Said
Bently Nevada Field
Application Engineer
Walid.Elsaid@ge.com

Mike Lockas
Bently Nevada Field
Application Engineer
Michael.Lockas@ge.com

Don Marshall
Bently Nevada
Product Manager
Donald.Marshall@ge.com

Billy Wise
Bently Nevada Field
Application Engineer
Billy.Wise@ge.com

THE SINGLE MOST TIME CONSUMING, AND OFTEN FRUSTRATING, PART OF STARTING OR MIGRATING A PORTABLE VIBRATION DATA COLLECTOR (PDC) BASED MACHINERY CONDITION MONITORING AND EVALUATION PROGRAM IS BUILDING THE DATABASE. A SKILLED USER COULD CONFIGURE WELL OVER 750 MACHINES AND IN SOME CASES AS MANY AS 2,500 MACHINES IN A SINGLE DAY. THIS ARTICLE DESCRIBES THE EASY WAY TO DO IT!

Bring Your Machinery Hierarchy in from CMMS, ERP or Other PDC Systems

Reliability professionals who use the SCOUT100 or SCOUT140 portable data collector with Ascent* software have a couple of tools available to them that make this process easy and painless. These tools also provide one very important attribute to your database – consistency. Your greatest success will come from using consistent data collection and evaluation methods across common machine type families in your facility.

Bently Nevada
Asset Condition Monitoring
Route
Measure
Record Review
Folders
Balance
Default Folder
SCOUT100

STEP 01

CREATING YOUR MACHINERY ASSET HIERARCHY IN ASCENT SOFTWARE

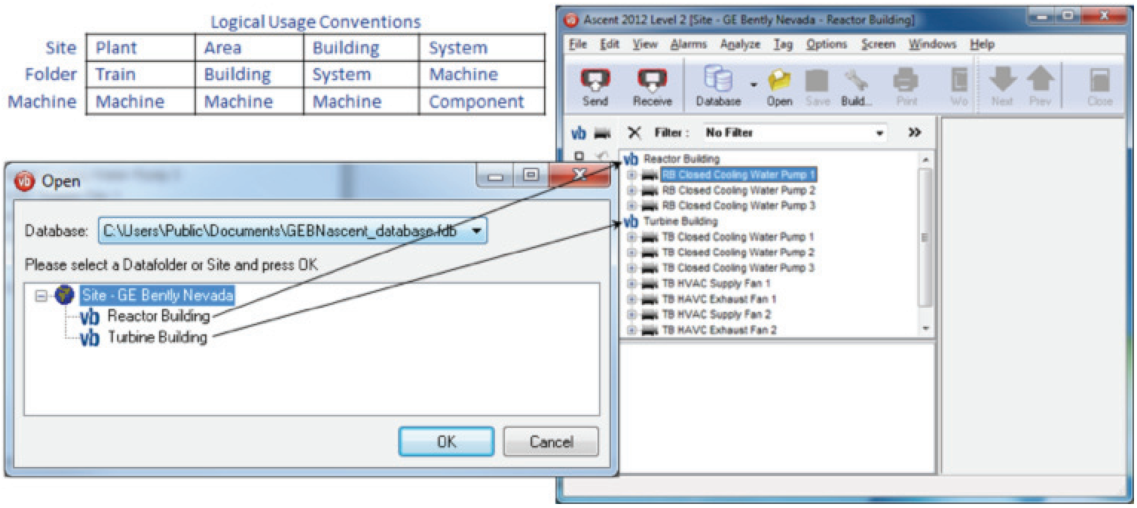
Contrary to popular belief, this is actually the easiest part of the process. No repetitive typing is required!

Your machinery asset hierarchy structure can be built from a spreadsheet. Nearly all CMMS, ERP or other supplier portable vibration monitoring systems have the ability to export machinery asset lists to a ".CSV" file or a spreadsheet, where each column represents a particular hierarchical attribute. The resulting spreadsheet can easily be restructured with simple column manipulation, copy and paste, to the proper format to be imported into the Ascent database.

The Ascent machinery hierarchy structure has four primary levels, starting at the database level with three internal levels named Site, Folder and Machine. (Multiple nested Site hierarchy levels can be used, but that capability is not pertinent to this discussion.) Most users will keep an entire facility or operating unit within its own database, so this discussion will focus on the lower three hierarchy levels. Figure 1 shows the Ascent hierarchy along with some potential logical uses for the levels. The top hierarchy level that opens in the Ascent workspace is the Site level and it shows the Folders that are within that site and can be expanded to show the machines within each folder. The Site structures must first be built into the database. The folders and machines will be created from the spreadsheet.

Spreadsheet setup is simple, as shown in Figure 2. A line entry is required for each machine with the Site name in Column A, Folder name in Column B and Machine name in Column C. When all of the machines are entered, sort the spreadsheet by Column A and Column B. Machines can be in any order you prefer once the spreadsheet is grouped by Site and Folder.

A set of Bently Nevada utilities and a master spreadsheet need to be installed on the Ascent computer.



Logical Usage Conventions

Site	Plant	Area	Building	System
Folder	Train	Building	System	Machine
Machine	Machine	Machine	Machine	Component

Open

Database: C:\Users\Public\Documents\GEBNascent_database.fdb

Please select a Datafolder or Site and press OK

- Site - GE Bently Nevada
  - Reactor Building
  - Turbine Building

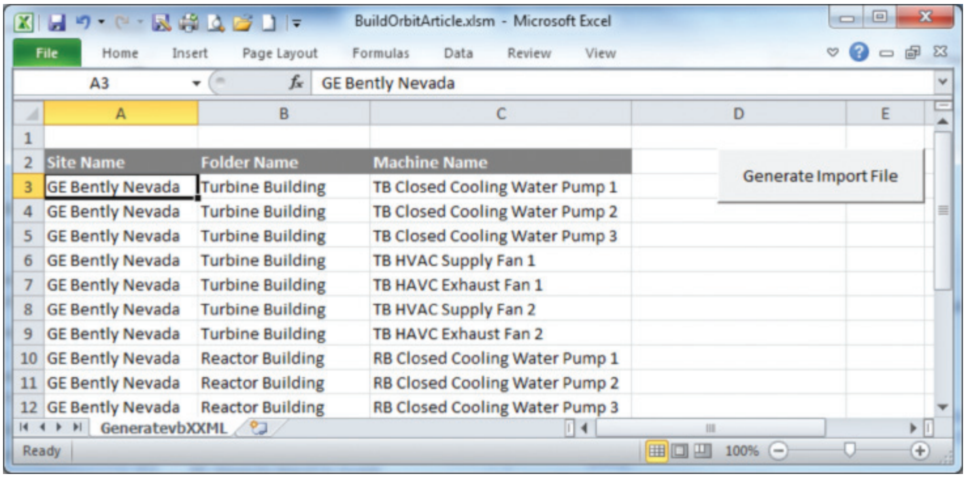
Ascent 2012 Level 2 [Site - GE Bently Nevada - Reactor Building]

Filter : No Filter

- Reactor Building
  - RB Closed Cooling Water Pump 1
  - RB Closed Cooling Water Pump 2
  - RB Closed Cooling Water Pump 3
- Turbine Building
  - TB Closed Cooling Water Pump 1
  - TB Closed Cooling Water Pump 2
  - TB Closed Cooling Water Pump 3
  - TB HVAC Supply Fan 1
  - TB HAVC Exhaust Fan 1
  - TB HVAC Supply Fan 2
  - TB HAVC Exhaust Fan 2

FIGURE 1: Ascent hierarchy example.

The hierarchy data is copied, being sure to only copy machines within the same Site, into the master spreadsheet, starting in Row 3. The master spreadsheet contains a macro that formats the the Site-Folder-Machine rows into an ".XML" file that can be directly imported into the Ascent database. Open the Site in Ascent and import the file that was just created. Repeat this simple process as needed for each Database-Site combination that needs to be built.



	A	B	C
1			
2	Site Name	Folder Name	Machine Name
3	GE Bently Nevada	Turbine Building	TB Closed Cooling Water Pump 1
4	GE Bently Nevada	Turbine Building	TB Closed Cooling Water Pump 2
5	GE Bently Nevada	Turbine Building	TB Closed Cooling Water Pump 3
6	GE Bently Nevada	Turbine Building	TB HVAC Supply Fan 1
7	GE Bently Nevada	Turbine Building	TB HAVC Exhaust Fan 1
8	GE Bently Nevada	Turbine Building	TB HVAC Supply Fan 2
9	GE Bently Nevada	Turbine Building	TB HAVC Exhaust Fan 2
10	GE Bently Nevada	Reactor Building	RB Closed Cooling Water Pump 1
11	GE Bently Nevada	Reactor Building	RB Closed Cooling Water Pump 2
12	GE Bently Nevada	Reactor Building	RB Closed Cooling Water Pump 3

FIGURE 2: Spreadsheet example.

STEP 02

CREATING CONSISTENCY WITH MACHINE TEMPLATES

The primary key to successful portable vibration based condition monitoring and evaluation program implementation is consistency – consistency of sensor placement from collection time to collection time as well as consistency of collection and alarm parameters from similar machine to similar machine. A comprehensive template for a four bearing machine can be built in less than 10 minutes!

Ascent software provides excellent tools to build machinery details, data collection parameters and alarm criteria completely manually or through the use of guided methods following internationally accepted industrial practices such as ISO 2372/ BS 4675 and ISO 10816/BS 7854, or the Technical Associates Proven Method (Reference 1). Along with the ability to copy, paste and rename, these tools are helpful when you are building a couple hundred machines or less in your database. The tools are especially useful when there are relatively few instances of the same machine configuration, or when you don't have the opportunity to pre-load your machinery asset hierarchy list.

Facilities with large numbers of machines, or a machine hierarchy structure that is exported and preloaded from a CMMS, ERP or other portable vibration program system, particularly where the same type of machine is used repeatedly, benefit from these guided methods. But the difference here is that these tools are used to create each specific machine type once. Each machine type is saved as a Template File into a library folder on your computer or network, where they are available to be used in multiple databases, and can easily be applied to multiple similar machines at the same time. Do this for every machine type that you need.

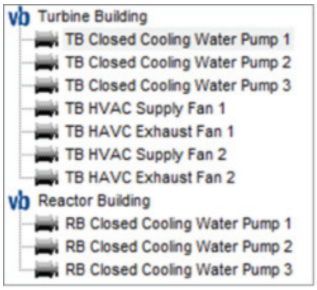
STEP 03

PUTTING HIERARCHY AND TEMPLATE STRUCTURES TOGETHER

Connecting the machine Templates to the already populated machine names simplifies the creation process and minimizes the opportunity for errors.

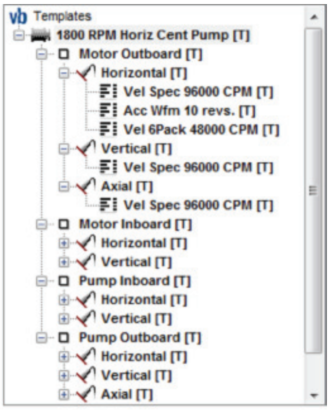
Consider the imported hierarchy structure and the machine structure built in Figure 3 and saved as a Template, along with other machine types in a Template Library. Right-click on the Folder name in the hierarchy and select Template, Import Template File to choose which Template to apply first. You will see a selection window that shows all of the machines in all of the Folders in the active Site, similar to Figure 4. Simply use the mouse to put a check mark in the box next to each machine where you want to use the Template you selected. Click the Apply button when you have completed your selections and within a few moments, those machinery assets will be fully setup in your database. A machine whose structure has been populated with a Template will be designated by [C] (for "child") to the right of the name as a visual clue that it is related to a Template.

Simply repeat the process to apply your other Templates to the rest of the machines in your database.

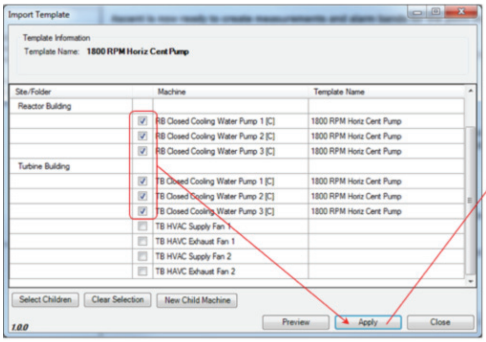

Turbine Building
TB Closed Cooling Water Pump 1
TB Closed Cooling Water Pump 2
TB Closed Cooling Water Pump 3
TB HVAC Supply Fan 1
TB HAVC Exhaust Fan 1
TB HVAC Supply Fan 2
TB HAVC Exhaust Fan 2
Reactor Building
RB Closed Cooling Water Pump 1
RB Closed Cooling Water Pump 2
RB Closed Cooling Water Pump 3

Imported Hierarchy Structure

FIGURE 3: Machine structure example.


Templates
1800 RPM Horiz Cent Pump [T]
Motor Outboard [T]
Horizontal [T]
Vel Spec 96000 CPM [T]
Acc Wfm 10 revs. [T]
Vel 6Pack 48000 CPM [T]
Vertical [T]
Vel Spec 96000 CPM [T]
Axial [T]
Vel Spec 96000 CPM [T]
Motor Inboard [T]
Horizontal [T]
Vertical [T]
Pump Inboard [T]
Horizontal [T]
Vertical [T]
Pump Outboard [T]
Horizontal [T]
Vertical [T]
Axial [T]

Created Template Structure

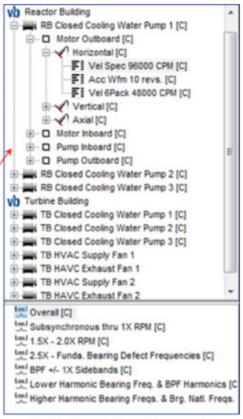

Import Template
Select Children
Clear Selection
New Child Machine
Preview
Apply
Close
1.0.0

Template Information
Template Name: 1800 RPM Horiz Cent Pump

Site/Folder		Machine	Template Name
Reactor Building			
	☑	RB Closed Cooling Water Pump 1 [C]	1800 RPM Horiz Cent Pump
	☑	RB Closed Cooling Water Pump 2 [C]	1800 RPM Horiz Cent Pump
	☑	RB Closed Cooling Water Pump 3 [C]	1800 RPM Horiz Cent Pump
Turbine Building			
	☑	TB Closed Cooling Water Pump 1 [C]	1800 RPM Horiz Cent Pump
	☑	TB Closed Cooling Water Pump 2 [C]	1800 RPM Horiz Cent Pump
	☑	TB Closed Cooling Water Pump 3 [C]	1800 RPM Horiz Cent Pump
	☐	TB HVAC Supply Fan 1	
	☐	TB HAVC Exhaust Fan 1	
	☐	TB HVAC Supply Fan 2	
	☐	TB HAVC Exhaust Fan 2	

Template Assignment

FIGURE 4: Example folders with machines.


Reactor Building
RB Closed Cooling Water Pump 1 [C]
Motor Outboard [C]
Horizontal [C]
Vel Spec 96000 CPM [C]
Acc Wfm 10 revs. [C]
Vel 6Pack 48000 CPM [C]
Vertical [C]
Axial [C]
Motor Inboard [C]
Pump Inboard [C]
Pump Outboard [C]
RB Closed Cooling Water Pump 2 [C]
RB Closed Cooling Water Pump 3 [C]
Turbine Building
TB Closed Cooling Water Pump 1 [C]
TB Closed Cooling Water Pump 2 [C]
TB Closed Cooling Water Pump 3 [C]
TB HVAC Supply Fan 1
TB HAVC Exhaust Fan 1
TB HVAC Supply Fan 2
TB HAVC Exhaust Fan 2
Overall [C]
Subsynchronous thru 1X RPM [C]
1.5X - 2.0X RPM [C]
2.5X - Funda. Bearing Defect Frequencies [C]
BPF +/- 1X Sidebands [C]
Lower Harmonic Bearing Freq. & BPF Harmonics [C
Higher Harmonic Bearing Freqs. & Brg. Natl. Freqs.

Fully Populated Hierarchy

Final Considerations

Machines whose internal measurement and alarm structure are created from Templates are considered as "Children" of the template itself. Changes made later to a Template are propagated to all of the child-machines of that Template globally. Machines that exhibit "normal" behaviors different than those expected by the Template can be designated "Free" from the template, enabling specific changes to made be exclusively on them, without altering the Template itself or parameters on any other machine in the database.

For those who are considering switching from another supplier's portable vibration monitoring equipment and software to a Bently Nevada SCOUT with Ascent system, please realize that historical data conversion from one system to another is never a good idea. Different data collectors acquire and process data differently (this is often true even within a single supplier's instrument family) and are optimized for performance differently. The best thing to do when changing from another supplier's system to a Bently Nevada system is to keep your previous software and database available for historical review and start fresh with the new system with a database optimized to support the system's strengths. You'll probably never look back at your old system after a few months working with your new one.

RECOMMENDED BEST PRACTICES

Always start with a fresh database (or databases) to optimize your machinery condition monitoring and evaluation program effectiveness

—

Export your machinery asset hierarchy from your CMMS, ERP or legacy PDC system

—

Group your machines into common categories

—

Build a template (or templates) for each machine category using The Proven Method or manually using other site specific standard practices

—

Match the machine templates to the hierarchy

THE PRIMARY KEY TO SUCCESSFUL PORTABLE VIBRATION BASED CONDITION MONITORING AND EVALUATION PROGRAM IMPLEMENTATION IS **CONSISTENCY** – CONSISTENCY OF SENSOR PLACEMENT FROM COLLECTION TIME TO COLLECTION TIME AS WELL AS CONSISTENCY OF COLLECTION AND ALARM PARAMETERS FROM SIMILAR MACHINE TO SIMILAR MACHINE.

TABLE

STEP	TIME IN MINUTES	COMMENTS
Prepare and Import Machinery Hierarchy Structure for 1,000 Machines	5 ½	User at the computer, but no text typing required[1]
Prepare Centrifugal Pump Template using The Proven Method with some site specific manual customization	8	User at the computer, limited text typing required
Match 655 of 1,000 Machines in the Hierarchy to the Centrifugal Pump Template (manual selection)	18 ½	User at the computer ticking check boxes, but no text typing required
Apply the Centrifugal Pump Template to the 655 Selected Machines (automatic, once started)	51	Computer working independently[2]

[1] The hierarchy was provided as a spreadsheet directly exported from the ERP system. Some structural manipulation was required.
[2] In a networked Ascent environment, the User could be simultaneously performing other tasks on another workstation.

Results You Can Achieve

Benchmark testing was performed using machinery from a USA Gulf coast refinery. The test contained a total of 1,000 machines that were exported from their ERP system. This sample included 655 similar centrifugal pumps.

These numbers demonstrate that a skilled Ascent user could easily and accurately configure close to 2,500 machines in a single workday. This method provides efficiency of initial hierarchy entry along with minimal opportunity for typographical errors thanks to the majority of the text entries coming directly from other source systems. Consistent machine naming among systems and departments saves time and reduces errors when directing maintenance and repair activities. Similar scaled results can be achieved with the application of additional machine templates to the remaining machines.

You are now ready to run your program to achieve the value your SCOUT portable vibration data collectors and your Ascent software can provide. Of course, your local Bently Nevada Field Service Engineer can always be available to assist you with starting your SCOUT and Ascent based condition monitoring program.

Reference

[1] The 'Proven Method' is a time-tested technique that specifies peak spectral alarm levels and frequency bands for measurements taken on healthy plant machinery. It was created by Technical Associates of Charlotte, P.C., and is available in Ascent software for establishing effective spectral alarm bands.

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